AMERICAN SOCIETY
FOR
TESTING MATERIALS.

AFFILIATED WITH THE
INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

PROCEEDINGS
OF THE
NINTH ANNUAL MEETING

Held at Atlantic City, New Jersey,
June 21, 22, 23, 1906.

VOLUME VI.

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THE COMMITTEE ON PUBLICATIONS.

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SUMMARY OF THE PROCEEDINGS OF THE NINTH ANNUAL MEETING.

ATLANTIC CITY, N. J., JUNE 21–23, 1906.

THE NINTH ANNUAL MEETING OF THE AMERICAN SOCIETY FOR TESTING MATERIALS was held at the Hotel Chalfonte, Atlantic City, N. J., on June 21–23, 1906. The total attendance at the meeting, including guests, was over 250.

The following members were present or represented at the meeting: W. A. Aiken; Ajax Metal Company, represented by G. H. Clamer; Victor S. Allien; American Bridge Company, represented by C. C. Schneider; American Foundrymen's Association, represented by Richard Moldenke; *American Machinist*, represented by Fred. J. Miller; Barrett Manufacturing Company, represented by Fred. L. Kane; Wesley J. Beck; James A. Beckett; A. W. Belden; Bethlehem Steel Company, represented by E. O'C. Acker; John Birkinbine; Ferdinand Bōcking; A. Bonzano; Cyrus Borgner; W. A. Bostwick; C. W. Boynton; Holstein DeH. Bright; John G. Brown; Samuel A. Brown; Jacob Cambier; Cambria Steel Company, represented by George E. Thackray; William Campbell; John A. Capp; Carnegie Steel Company, represented by W. A. Bostwick; F. D. Carney; Frank P. Cheesman; James Christie; Cincinnati Chapter, American Institute of Architects, represented by A. O. Elzner; Colorado Fuel and Iron Company, represented by Jacob Cambier; E. A. Condit, Jr.; Fillmore Condit; P. H. Conradson; Edgar S. Cook; Harry C. Crawford; O. C. Cromwell; Robert A. Cummings; Allerton S. Cushman; Nathan H. Davis; William M. Davis; Edward W. DeKnight; Cyril DeWyrall; H. E. Diller; D. E. Douty; A. W. Dow; W. C. DuComb, Jr.; H. O. Duerr; W. O. Dunbar; Frank D. Easterbrooks; A. O. Elzner; *Engineering Record*, represented by John M. Goodell; R. W. Evans; S. M. Evans; A. I. Findley; C. N. Forest; William Forsyth; H. W. Foster; James B. French; William B. Fuller; John Lathrop Gray; Russell S. Greenman; Ed. D. Gregory; W. H. Ham; E. L. Hancock; Elwood S. Hand; W. H. Harding;

Arthur B. Harrison; Henry J. Hartley; G. B. Heckel; E. Lee Heidenreich; George P. Hemstreet; R. W. How; James E. Howard; Henry M. Howe; E. A. Hughes; Richard L. Humphrey; Charles L. Huston; E. T. Ickes; Illinois Steel Company, represented by P. E. Carhart; F. P. Ingalls; International Acheson Graphite Company, represented by E. C. Sprague; *Iron Trade Review*, represented by A. Van Zwaluwenburg; John M. Jeffers; Robert Job; William Jordan, Jr.; Edgar B. Kay; R. S. Kellogg; J. A. Kinkead; Morris Knowles; Paul Kreuzpointner; Frederic A. Kummer; Lackawanna Steel Company, represented by F. E. Abbott; Gaetano Lanza; W. W. Lemen; Harry J. Leschen; Robert W. Lesley; John F. Lewis; H. H. Linton; H. C. Loudenbeck; Lowe Brothers, represented by Houston Lowe; John Lucas and Company, represented by W. I. Lewis; Lukens Iron and Steel Company, represented by Charles L. Huston; T. D. Lynch; Ernest B. McCready; J. A. McFarland; Charles F. McKenna; Frank P. McKibben; D. W. McNaugher; Charles Major; Edgar Marburg; S. M. Marshall; Richard K. Meade; Mansfield Merriman; Rudolph P. Miller; Leon S. Moisseff; Richard Moldenke; National Tube Company, represented by Frank N. Speller; E. D. Nelson; William A. Noyes; Tinius Olsen; Osborn Engineering Company, represented by Frank C. Osborn; Logan Waller Page; W. M. Parks; Ludington Patton; Pennsylvania Steel Company, represented by F. D. Carney; A. A. Phlegar, Jr.; W. A. Polk; Charles E. Price; H. H. Quimby; *Railroad Gazette*, represented by R. C. Davidson; *Railway and Engineering Review*, represented by Willard A. Smith; J. C. Ramage; Reading Iron Company, represented by Geo. Schuman; Geo. N. Riley; S. M. Rodgers; John A. Roebling's Sons Company, represented by H. J. Horne; Joseph Royal; F. E. Schmitt; C. C. Schneider; Archie W. Schwartz; W. T. Sears; J. M. Sherrerd; Charles Shults; Jesse J. Shuman; D. G. Sinclair; C. E. Skinner; E. B. Smith; J. P. Snow; Solvay Process Company, represented by George B. Hartley; C. W. Somerville; Henry S. Spackman Engineering Company, represented by E. W. Lazell; C. R. Spare; W. L. Sperry; Standard Steel Works, represented by Holstein DeH. Bright; F. M. Stapleton; J. T. Stephenson; P. M. Stewart; E. Platt Stratton; George F. Swain; Howard Taggart; Arthur N. Talbot; William P. Taylor; A. R. Thomas; Gustave W. Thomp-

son; Sanford E. Thompson; C. J. Tilden; Maximilian Toch; N. B. Trist; C. P. Van Gundy; Charles H. Vannier; S. S. Voorhees; Charles L. Wachter; Samuel T. Wagner; Joseph F. Walker; Lee W. Walter; C. E. Ward; George S. Webster; William R. Webster; Paul Weeks; G. D. White; Max H. Wickhorst; Winchester Repeating Arms Company, represented by R. L. Penny: N. B. Wittman; R. D. Wood and Company, represented by Walter Wood; Walter Wood; Ira H. Woolson; Joseph R. Worcester; P. L. Wormeley, Jr. Total number, 188 (including representations); total number in personal attendance, 179.

FIRST SESSION.—THURSDAY, JUNE 21, 3 P. M.

Business Meeting.

Vice-President Robert W. Lesley in the chair.

The minutes of the Eighth Annual Meeting were approved as printed.

The annual report of the Executive Committee was adopted as printed.

The Chair appointed Mr. A. W. Dow and Mr. Richard L. Humphrey as tellers to canvass the ballot for officers.

A paper entitled "Memoirs of Deceased American Investigators who have Contributed in a Marked Degree to the Advance of the Testing of Materials," was read by Mr. Gaetano Lanza.

On motion, a vote of thanks was extended to Mr. Lanza in appreciation of his work in compiling the memoirs.

The annual report of Committee H on Standard Tests for Road Materials, L. W. Page, Chairman, was read and passed to publication.

The following two papers were then presented:

"The Development of the Test for the Cementing Value of Road Materials." Allerton S. Cushman.

"Notes on the Hardness and Abrasion Tests of Road Materials." P. L. Wormeley, Jr.

The annual reports of the following standing committees were read, discussed and referred to publication:

Committee L, on Standard Specifications and Tests for Clay and Cement Sewer Pipes. Rudolph Hering, Chairman.

Committee P, on Fireproofing Materials. Ira H. Woolson, Chairman.

Committee Q, on Standard Specifications for the Grading of Structural Timber. Herman Von Schrenk, Chairman.

The tellers reported that 140 legal ballots had been cast for officers and in accordance with their report the Chair declared the election of the following officers:

CHARLES B. DUDLEY, *President.*
ROBERT W. LESLEY, *Vice-President.*
EDGAR MARBURG, *Secretary-Treasurer.*
HENRY M. HOWE, *Member of Executive Committee.*
JAMES CHRISTIE, *Member of Executive Committee.*

The meeting then adjourned till 8 P. M.

SECOND SESSION.—THURSDAY, JUNE 21, 8 P. M.

Vice-President Robert W. Lesley in the chair.

The chairman invited Mr. Henry M. Howe to the chair and read the Annual Address on "The American Society for Testing Materials—Its Past and Future."

A paper on "The National Bureau of Standards," by S. W. Stratton, was, in the absence of the author, read by title.

The following papers were then read and discussed:

"Concrete Column Tests at Watertown Arsenal." J. W. Howard.

"Some Effects of Earthquake Shock and Fire on Materials and Buildings at San Francisco." Richard L. Humphrey.

The meeting then adjourned till the following morning.

THIRD SESSION.—FRIDAY, JUNE 22, 10 A. M.

Section on Iron and Steel.

Mr. Henry M. Howe in the chair.

The following papers were read:

"The Corrosion of Steel as Affected by its Chemical Composition" J. P. Snow.

"Electrolytic Corrosion of Steel." Maximilian Toch.

A Topical Discussion on "The Corrosion of Iron and Steel" was introduced by Messrs. Henry M. Howe, Allerton S. Cushman and James Christie.

On motion, it was resolved that the Executive Committee be instructed to consider the appointment of a Committee on "The Corrosion of Iron and Steel."

The annual report of Committee F on "Heat Treatment of Iron and Steel," was then presented by Mr. Henry M. Howe, Chairman.

In the absence of the author a paper on "The Burning, Overheating and Restoring of Nickel Steel," by G. B. Waterhouse, was read by title.

Mr. William Campbell read a paper on "The Effect of Heat Treatment on High Carbon Steels."

A paper on "The Beneficial Effect of Adding High-Grade Ferro-Silicon to Cast Iron," by Alex. E. Outerbridge, Jr., was read by title.

The meeting then adjourned till 3 P. M.

Section on Cement and Concrete.

Vice-President Robert W. Lesley in the Chair.

The annual report of Committee I on Reinforced Concrete was presented by Mr. R. L. Humphrey in the absence of the Chairman, Mr. F. E. Turneaure.

The following papers were then read and discussed:

"Tests of Reinforced Concrete Beams." Gaetano Lanza.

"Tests of Reinforced Concrete Beams." S. J. Tilden.

"Notes on Compression Tests of Cement." W. P. Taylor.

"Consistency of Concrete." Sanford E. Thompson.

A paper by Mr. Clifford Richardson on "The Present Status of Our Knowledge in Regard to the Constitution of Portland Cement," was, in the absence of the author, read by title.

A paper on "Progress made in the Investigation of Structural Materials During the Fiscal Year Ending June, 1906," by Mr. Richard L. Humphrey, was presented by title.

The meeting then adjourned till 3 P. M.

FOURTH SESSION.—FRIDAY, JUNE 22, 3 P. M.

Section on Specifications for Iron and Steel.

Committee A on Standard Specifications for Iron and Steel, Wm. R. Webster, Chairman, presented a report on the proposed revised Standard Specifications for Steel Rails.

On motion the report was referred back to Committee A with instructions to report at the next Annual Meeting proposed Standard Specifications for Steel Rails which will give promise of correcting as far as possible the defective quality of rails obtained under existing specifications.

On motion the Chairman of Committee A was instructed to address such recommendations to the Executive Committee as would be best calculated, in his judgment, to facilitate the work of the Committee.

A Discussion on "Standard Specifications for Ship Material" was then opened by Mr. E. Platt Stratton and Mr. Wm. R. Webster.

On motion the question of Standard Specifications for Ship Material was referred to the Executive Committee.

The following two papers were then read and discussed:

"Fire-box Steel—Failures and Specifications." Max H. Wickhorst.

"Experiments on the Segregation of Steel Ingots in its Relation to Plate Specifications." C. L. Huston.

The meeting then adjourned till the following morning.

Section on Preservative Coatings.

Mr. G. B. Heckel in the chair.

The annual report of Committee E on Preservative Coatings for Iron and Steel, S. S. Voorhees, Chairman, was read, discussed and passed to publication.

The following papers were then read and discussed:

"Protective Coatings for the Preservation of Steel." Arthur B. Harrison.

"Practical Testing and Valuation of Japan." Robert Job.

A paper on "Testing of Shellac Varnish," by A. C. Langmuir, was, in the absence of the author, read by title.

Mr. G. W. Thompson read certain letters addressed to Mr. J. W. Whitehead on the subject of sandblasting.

The meeting then adjourned till the following morning.

FIFTH SESSION.—SATURDAY, JUNE 23, 10 A. M.

Section on Metals and Fuels.

Mr. Henry M. Howe in the chair.

The annual reports of the following committees were read and accepted:

Committee B, on Standard Specifications for Cast Iron and Finished Castings. Walter Wood, Chairman.

On motion Committee B was authorized to confer with the committees on Specifications for Cast Iron Pipe of the Water Works Associations with a view of harmonizing results.

Committee J, on Standard Specifications for Foundry Coke. Chas. H. Zehnder, Chairman.

Committee M, on Standard Specifications for Staybolts. H. V. Wille, Chairman.

Committee O, on Uniform Speed in Commercial Testing. Paul Kreuzpointner, Chairman.

On motion the question of instructing Committee O to recommend standard speeds for testing machines, was referred to the Executive Committee.

Committee T, on the Tempering and Testing of Steel Springs and Standard Specifications for Spring Steel. J. A. Kinkead, Chairman.

Committee R, on Uniform Specifications for Boilers. E. D. Meier, Chairman.

A paper by J. A. Holmes on "Some Results of the Government Fuel Tests at St. Louis," was, in the absence of the author, read by title.

Mr. F. P. McKibben then read a paper on "Tension Tests of Steel Angles."

The meeting adjourned till 3 P. M.

Section on Cement, Concrete and Asphalt.

Vice-President Robert W. Lesley in the chair.

The following papers were read and discussed:

"Investigation of the Conductivity of Concrete and the Effect of Heat upon its Strength and Elastic Properties." Ira H. Woolson.

"The Determination of the Specific Gravity of Cements." R. K. Meade.

"A New Device for the Mechanical Sifting of Concrete Aggregates." C. N. Forrest.

"Some Sand Experiments Relating to Per Cent. of Voids and Tensile Strength of Cement Mortars." J. Y. Jewett.

"Relation between Some Physical Properties of Bitumens and Oils." A. W. Dow.

"The Proximate Composition and Physical Structure of Trinidad Asphalt with Special Reference to the Behavior of Mixtures of Bitumen and Clay." Clifford Richardson.

The meeting adjourned till 3 P. M.

SIXTH SESSION.—SATURDAY, JUNE 23, 3 P. M.

On Waterproofing, Testing Machines and Miscellaneous Subjects.

Mr. Gaetano Lanza in the chair.

Mr. E. L. Hancock read a paper on "The Effect of Combined Stresses on the Elastic Properties of Iron and Steel."

The following two papers were then read and discussed jointly:

"Report of Committee S on Waterproofing Materials." W. A. Aiken, Chairman.

"Some Mistakes in Waterproofing." E. W. DeKnight.

The annual reports of the following standing committees were then read and accepted:

Committee K, on Standard Methods of Testing. Gaetano Lanza, Chairman.

Committee G, on The Magnetic Testing of Iron and Steel. Walter J. Esterline, Chairman.

Mr. W. C. DuComb, Jr., read a paper on "New Features of Two Large Testing Machines."

The following papers were then read by title:

"Methods of Testing Cements for Waterproofing Properties." W. P. Taylor.

"The Purdue University Impact Machine." W. K. Hatt and W. P. Turner.

"A Complete Equipment for Magnetic Testing." Walter J. Esterline.

"Mechanical Experiences with Limber and Stiff Rail Sections." P. H. Dudley.

"Tests of Metals in Reverse Torsion." E. L. Hancock.

"Additional Data on the Rattler Test for Paving Brick as Disclosing the Limit of Permissible Absorption." Edward Orton, Jr.

On motion the recommendation of Committee E that funds for the prosecution of its investigations be obtained by subscriptions solicited in the name of the Society was referred to the Executive Committee.

On motion of Mr. Walter Wood, it was recommended to the Executive Committee to consider the desirability of authorizing one of the American members expecting to attend the Congress of the International Association to act as the accredited representative of the American Society and also to send a suitable message of greeting and goodwill to the International Association in Congress assembled.

On motion of Mr. Paul Kreuzpointner it was resolved, that the Executive Committee be instructed to consider the appointment of a Committee on Standard Specifications for Chain Iron and Steel, Chains and Chain Cables.

A paper entitled "High Carbon Wire Fabric for Use in Reinforced Floors, Girders, Beams and Columns," by Mr. E. Lee Heidenreich, was then read by title.

On motion of Mr. James Christie the following congratulatory message to the President was unanimously adopted by a rising vote:

To CHARLES B. DUDLEY, Ph. D.,
President, American Society for Testing Materials.

SIR:—Your fellow members of the Society, in Convention assembled at the Ninth Annual Meeting in Atlantic City, desire to offer you their hearty congratulations upon the change in your domestic relations which you have recently consummated.

That the new life you have begun will be productive of prosperity and happiness, is our hope and belief.

While offering our felicitations to both you and Mrs. Dudley, we take the opportunity to thank you sincerely for your past efforts for the advancement of the Society, and trust that you will be enabled to continue the good work for many years to come.

By order of the Convention,

EDGAR MARBURG,
Secretary.

The Chair then declared the meeting adjourned *sine die.*

American Society for Testing Materials.

AFFILIATED WITH THE
INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

PROCEEDINGS.

This Society is not responsible, as a body, for the statements and opinions advanced in its publications.

THE AMERICAN SOCIETY FOR TESTING MATERIALS: ITS PAST AND FUTURE.

ANNUAL ADDRESS BY ROBERT W. LESLEY, VICE-PRESIDENT.*

At this, the ninth annual meeting of our Society, it has been deemed advisable that something should be said as to the history, the work, and the purposes of the Association of which you are all members. To those of us who for years have known our worthy President, Dr. Dudley, and to those who recently have become acquainted with him as President of this Society, his wonderful ability and great modesty are familiar traits. With these facts in mind and especially that modesty which seems covered in good works rather than in words, it can be readily understood why our President should have sought refuge in marriage and a wedding tour in Europe, rather than to be here to-day, telling what the Society of which he is one of the founders and of which he is to-day, the honored President, has been and is doing, Equally modest and equally diffident, but by no means so able, I feel to-day somewhat overwhelmed with the task that has been put upon me. It is, however, a call of duty to which I cannot refuse to respond, and further, it is a great pleasure to one of the old "war-horses"

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*Owing to the unavoidable absence of the President, the annual address was presented by the Vice-President.

of the Society for Testing Materials to be able to tell you a little about our work.

Known as the American Section of the International Association for Testing Materials, our organization had its birth at the Engineers' Club of Philadelphia on June 16, 1898, where some twenty members assembled at the call of Mr. A. C. Henning, member of the Council of the International Association. Our first Chairman was Professor Mansfield Merriman, of Lehigh University. The Vice-Chairman was Professor Henry M. Howe, of Columbia University; the Secretary, Mr. R. L. Humphrey; the Treasurer, Mr. Paul Kreuzpointner. These officers, together with Mr. Henning, were appointed as an Executive Committee with full power to designate the American representatives for all the International Committees on technical problems.

The first annual meeting of the American Section was held at the Engineers' Club, Philadelphia, August 27, 1898, for the purpose of completing a permanent organization by the adoption of by-laws, etc.

This was the child that is grown into the man of to-day, and at this first meeting at which only about ten members were in attendance, the old "war-horses" of the Society, Dudley, Hatt, Henning, Howe, Marburg, Merriman, Moldenke and Webster were present, and the total membership was reported to be 70. The proceedings were very short, and according to the minutes the principal testing was done in the shape of testing the cuisine of the Hotel Lafayette in Philadelphia, and eating a dinner in honor of the occasion. In considering our Association whose membership was so small, and which has grown so greatly, we may divide its life, so far as we know it, into three epochs or periods. The first, the epoch of childhood. That time in the life of our Society may be said to be represented by the contents of Volume I of our Proceedings, which cover the years from 1898 to 1902, and embrace in their telling some 288 pages. The book that I have before me tells of the beginning of our Society, of the early annual meetings at Philadelphia, Pittsburg, New York, and Niagara Falls. It tells of the relations to its good old mother, the International Association of Testing Materials, whose home is in Europe and whose wings were all too weak to cover her offspring in many distant parts of the world. Her American child

(our Society), brought into being under the high-pressure period or prosperous years of 1898–1902, was a nervous and high-strung child, desirous of doing many things and doing them quickly; a child which stood to have its own way, resenting the advisors, examiners, governesses, etc., that the old mother sought to impose upon it, and resenting the methods that the old mother sought to bind it with. The early history of this American Section tells a tale of child's diseases met and successfully combatted, of little rifts in the relations with the parent Society in Europe, of little differences in methods of management and purposes. This first volume tells of all this and yet contains much of important work, much of specifications, much of committees appointed, much of serious, earnest learning and arduous labors. In these early days of our Society we found that our good old mother abroad did not seem to deal with the practical side of matters as we wanted to deal with them in our strenuous American way. The International Association of Testing Materials dealt with problems—we wanted to deal with specifications. Our early volume is filled with problems which committees, representing all the nations of Europe and our own good American nation were to investigate and pass upon. An examination of these problems involved deep research, involved pursuit into the rarified atmosphere of science to the utter neglect of the commercial factor which might be found in the making of specifications. At this time too there came along some discussion over the right of the American body to select its own member of Council in the International Association, and this led to considerable discussion with the good old mother in Europe, and in a measure reminded one of the "Boston Tea-Party" and its attending incidents. However, at the Buda Pesth Congress, in 1901, which was attended by our distinguished friend, Mr. Henry M. Howe, member of the Council and Chairman of the American Section, many of these matters which had been discussed between the American Section and the parent Society were gone into fully, and while on certain points some slight differences remained, the report was made that in general the tone of the members of the International Council was in the highest degree conciliatory and cordial and that their wish was to place the relations between the two Societies on the most friendly basis. These early meetings, during the period covered from 1898 to

1902, show the following to have been about the state of the Society:

	1898.	1899.	1900.	1901.	1902.
Membership	70	128	158	168	175
Cash receipts	.....	$297	$389.50	$370.65	$408.28
Pages of proceedings	.....	72	112	78	4
Attendance at annual meetings	10	28	20	19	75

The annual meetings, it will be noted, were distinguished by features that in the present busy days no longer mark them. There were in several cases excursions to industrial works, examination of testing laboratories, and in other cases social reunions and dinners attended by all the members. The Society was small, the number of papers presented was limited, the proceedings were reported in the form of bulletins instead of in the form of annual reports as is now the case and the membership remained, as will be seen above, practically stationary. The two annual addresses of Professor Merriman at the meetings in Pittsburg, in 1899, and New York, in 1900, were replete with information of value to the testing engineer and descriptive of the work done by the International Association. The saddest thing in the address at Pittsburg was the statement that the American Section, as already stated, had no income during 1898, "and the report of our Treasurer shows that during the present year the amount available for expenses has been about $120.00," and the next year showed even a sadder state of facts in the form of a deficit of $21.52.

In these addresses and the discussion of these meetings was brought out the fact that the main object of the International Association was to establish standard rules of testing, while the purpose as outlined during the childhood days of the American body was to enunciate specifications. This seemed to be the material point of difference between the Societies. While the American Society disavowed the fact that it would have any responsibility for these specifications and claimed that the report of a committee should be considered from the same point of view as that of the individual member, yet the International Society felt that even this was going too far, and it was at the New York meeting of 1900 that Professor Merriman brought out the thought of our

own national organization, suggesting there should be an American body, pursuing its own aims, and that the International Association should unify and correlate the views of national sections in various parts of the world. It was at this meeting that practically a reorganizing of the body was had, making changes in the by-laws, and practically creating the same offices that now exist, an organization which time has shown to be very effective and well adapted to the purposes of our Society. The principal business at this meeting consisted of discussions and examinations into the reports of the various committees, and there were practically no papers presented.

The fourth annual meeting was held at Niagara Falls, at the time of the Pan-American Exposition, and needless to say, in view of the pressure of many attractions of that great Exposition, and the many interests in connection therewith, the meeting was a short one. Professor Howe, the Chairman, in his address struck the keynote of the Society's business, referring to specifications as things which lessen the cost, the labor, and the friction in transporting of things from seller to buyer, and stating, "that our work is in fact to lessen the friction of the sale of materials of construction and thus to do our share in lowering the cost and eventually the price of the materials. And since every class must use things made with, or by, or transported with or by, these materials, our work makes, in the way I have sketched, for the bettering, the widening, the uplifting of the family life and the family surroundings of every class."

In this brief summary of the childhood days of our Society, it can be readily seen how difficult it was to build upon the American Continent, three thousand miles away from the home of the mother Society, an organization which could successfully cope with the practical American problem of testing and specifications. It can also be seen in the proceedings that the child's diseases were met and surmounted and how the child (the American Section of the International Association for Testing Materials) showed its right to exist, and to emerge from childhood into the lusty activity and vigor of youth. This period in our Society's life may be said to be covered by the three large volumes of Proceedings, representing the work of the years 1902–3–4—large books of five or six hundred pages, each filled with able

papers replete with interesting information of value to consumer, producer, and engineer, and representing the active, healthy, lusty strength of a young and vigorous American organization. This new life began at mother's suggestion that in order that our American organization should have its fullest development, a national society should be organized here.

During the winter of 1902, a change was made in the Secretaryship, Professor Edgar Marburg, of the University of Pennsylvania, having accepted the office tendered him by the Executive Committee. In taking this office, he wrote a letter under date of March 8, 1902, which is almost prophetic in its utterances. Referring first to the changing of the name of the Society, and the suggestion of Professor Tetmajer, of the International Association, that the American branch should be organized as a national body and apply for membership in the parent Society as a body, and he recommended that the name should be that of American Society for Testing Materials and that we should join the International Society as a unit instead of merely as individuals. Referring to the "future policy," Professor Marburg said: "This I conceive to be the most important topic for our immediate, earnest consideration. Manifestly the first concern should be to secure at least a moderate working fund. The next, to initiate a carefully conceived, but vigorous policy calculated to accomplish useful results. The objects for which we stand are of such far-reaching interest and importance that a separate organization for their furtherance will be seen to be amply justified, provided the many sided opportunities offered be adequately exploited. To present the matter categorically:

"First. Our Society should serve as the logical outlet for important individual contributions on the part of American scientists and engineers to knowledge of the materials of engineering and appliances used for their determination—be it along physical, chemical, or microscopic lines.

"Second. The standardization of methods of testing and the unification of specifications should be effectively promoted by the work of our own Committees, and by judicious cooperation with the committees of other organizations.

"Third. Our Society should afford unique opportunities for the meeting on common ground of manufacturers, engi-

neers and large consumers. In the broad sense, their interests are not conflicting ones, and every step toward their better reconciliation will be of mutual advantage.

"Fourth. Our Society furnishes the only medium for establishing closer relations with similar interests in other countries, and thus arriving at a better understanding on questions affecting the commercial exchange of products.

"Fifth. In recognition of the foregoing, the manufacturers may be properly expected not only to contribute generously towards the legitimate expenses of our Society, but to place their products and so far as possible, their facilities at our disposal in a reasonable measure, and free of cost, with a view of enabling our Committees to prosecute important investigations."

With these suggestions in mind, and with the full approval of the Executive Committee, the officials of the Society proceeded to take out a Charter under the laws of Pennsylvania, for the American Society for Testing Materials, and prepared to bring the matter of the inauguration of our new Society before the body at the convention at Atlantic City, in June, 1902.

At this, the fifth annual meeting, which was held at the Hotel Traymore, Atlantic City, on June 12, 13, and 14, there was the largest attendance that had ever been present at any of the annual gatherings of the Society. It was at this meeting that the child took upon itself the duties and responsibilities of youth. It became an American Society in name and in purpose, always "affiliated with the International Association for Testing Materials," its mother in the far-off land, always loyal to its dear old mother and always appreciative of the good work she was doing in her own country and in her own way. At this meeting, the charter recommended by the Executive Committee was unanimously adopted, all the members of the American Section were elected members of the new Society, by-laws were adopted and a permanent organization founded, under the constitution which had just been adopted, and at this meeting, the Society emerged, full-fledged, strong, and vigorous, with a membership doubled in number and resources practically doubled in volume. At this convention begins the history of the second period of our Society, a period of youth, of healthy, strong, vigorous lusty development under American lines, American purposes, still affiliated with the

parent Society, but pursuing its own way, under its own lines of development. This period embraces the three years of 1902, 1903, and 1904, and the early part of the year 1905. It is marked by the following figures:

	1902.	1903.	1904.	1905.
Membership	175	349	485	677
Pages of publication	4	388	490	655
Receipts	$408.28	$3952.83	$5215.68	$5556.48
Attendance at annual meetings	75	100	175	200

and it is marked further by development that has seldom, if ever, been exceeded by any scientific society in the world. At this period "problems" give way to "specifications"—theories give way to actualities. An hypothesis gives way to the fact and results take the place of vague discussions; the English language takes the place of the French and German, in which the previous publications had been published. All this is well outlined in the annual address of Professor Howe, who, referring to the new organization, mentions the importance of a permanent secretary, and the value of his work. He also says that "the business of the Society is making specifications and not merely dealing with methods of testing." This is well expressed in the charter which states that the corporation is formed "for the promotion of knowledge of the materials of engineering, the standardization of specifications and methods of testing." At this meeting, which lasted for three days, and was marked by the presentation of numerous papers on iron, steel, cement, asphalts, and other kindred subjects, there were presented reports of the various Committees of the Society, and among them that of Committee C on the making of cement specifications. This report first indicated one of the great purposes outlined in Professor Marburg's suggestion, and carried out, as in the case presented, namely, the cooperation through our Society of various other engineering societies in the preparation and standardizing of specifications. To the Committee of our Society, the entire Committee on the "method of manipulation of cement tests" of the American Society of Civil Engineers, as well as those of the American Railway Engineering

and Maintenance of Way Association and of the Association of Portland Cement Manufacturers, were added, and in this way the fullest cooperation of the scientific bodies having to do with the matter in hand was secured toward the furtherance of the desired end. It is noticeable that the proceedings of this convention, issued as a single volume, contained 388 pages against an average output of sixty-seven pages per annum during the previous four years of the Society's existence, and that the membership during the year 1902 doubled, rising from 175 to 349 members, which was the membership at the sixth annual meeting held at the Delaware Water Gap, July 1, 2, and 3, 1903. Noticeable at this meeting was the increased membership above stated, and the large attendance of upwards of 100 persons; the dividing of the convention, owing to the pressure of important papers, into two sections, holding meetings in separate rooms. There was a further recognition of joint cooperation with other societies in the resolution for the appointment of a Committee on Reinforced Concrete Construction to act in connection with a similar committee of other bodies. The meeting was also marked by the high standard and important character of the scientific papers presented. Still following the lines of the prediction of our Secretary the report of the Executive Committee of this year showed receipts of over $4,000, and contained the statement: "At the present rate of growth, the Society should become self-sustaining within a few years with a moderate increase of dues."

At this convention, the first of that remarkable series of papers upon the philosophical and scientific side of testing materials was made by our distinguished President, Dr. Charles B. Dudley. There was also adopted at this convention, a resolution which stands for fair play and fair dealing, and which has been one of the secrets of success of our Society, namely:

First. That on all standing committees concerned with subjects involving commercial interests an equal numeric balance shall be preserved between engineers, scientists, and the representatives of the consumers on the one hand, and manufacturers or their representatives on the other.

Second. That the permanent chairmanship shall be vested in a member belonging to the former class, duly elected by the Committee.

The seventh annual convention was held at Atlantic City, June 16, 17, and 18, 1904, at which the attendance was 175. The proceedings of this year which cover 655 pages tell a tale of the development of the Society. Rarely, if ever, have there been as many papers on the subject of testing materials, as were presented at the convention in question. At this meeting a number of specifications were presented and sent out to a letter ballot, among them specifications for cement, for foundry pig iron and for malleable castings. At this convention too, more cooperation was shown with other scientific societies by referring back after considerable discussion the report of Committee A, for the purpose of endeavoring to secure an agreement between our Society and the other scientific societies, having to do with the matters involved. On this occasion two more important papers upon the very important question of testing were read, namely: "On the Influence of Specifications upon Commercial Products," which was the subject of the annual address of President Dudley, and "Testing in the United States," which was the subject of a most important paper presented by Professor Lanza.

During this period of the youth of the organization, the Society made it a prerequisite to membership that the applicant should be a member of the International Association for Testing Materials, and required that out of the annual dues received, from each of its members, the sum of $1.50 should be paid to the International Society. During this period, the International Society proposed various other conventions which were to follow the convention held in Buda Pesth, in 1901. In pursuance of the action of the Buda Pesth Congress, the next Congress should have been held in 1903. This was postponed upon the ground that it would give the Committee a better opportunity to complete their business. The Third Congress, which should have been held in St. Petersburg in 1904, was postponed till the following year. Another postponement of this Congress to Brussels, in 1905, was proposed, but this was again postponed and finally fixed for Brussels in 1906. Thus, for a period of four years, the American Society, paying annual dues to the International Society, received practically no benefit other than the minutes of the Third Congress and some few stray publications. With these facts before the American Society and with the develop-

ment of the American Society, with its own needs and its own requirements, the time arrived when the youth emerged into the man, and found himself needing all his means to meet the demand upon his own purse. Your Society was like a young man about to marry, who feels the responsibility of the world upon him and strains every nerve to provide the means to meet the necessary expenditures. At this period of his life he began to realize, though none the less lacking in loyalty to his old mother Society abroad, that the responsibilities of his own family were more pressing and more exacting than the sentiments of devotion to mother, 3,000 miles away. Meeting the contingency, in the way we Americans do, the Society at this Convention passed resolutions leaving it to the option of the individual members as to whether or not they should belong to the International Association with the attending dues, or, in other words, eliminated the requirement, that to be a member of the American Society for Testing Materials, it was necessary also to be a member of the International Association for Testing Materials, together with the payment of the dues incumbent thereon. In support of this it was claimed that the effect would be to increase the revenue of the Society about $1,000, and make the body almost self-supporting, to free it from the necessity of reception of contributions, and to make it absolutely independent in every respect. It was, however, stated that as many members as desired could remit their annual dues to the International Association of Testing Materials through the American Society and thus retain their membership as individuals. The matter was discussed at considerable length and the resolution was finally carried, the American Society as a body retaining its membership in the International Association for Testing Materials, and making an annual contribution of not less than $100 to the general funds of that Association. At this time begins the third period in the life of our Society—the period of manhood, of full growth, and of full development of membership of its own, and of freedom, bound only by the tie of sentiment to the mother society in Europe. This period is in our hand, and it is for us to meet it and do with it, seeking so far as possible to carry out the purposes and objects so thoroughly outlined in the Secretary's letter of March, 1902.

A RETROSPECT.

Our Society's Growth.

Today's report of the Executive Committee furnishes us information as to what the Society has done in the past year. First appears the growth of membership from 1898 to the present date. These figures speak for themselves and show healthy, vigorous growth. The attendance at the annual conventions shows that from a beginning, in 1898, of ten members, there will be present here to-day at this meeting not less than two hundred and fifty.

The finances which were referred to in Professor Merriman's annual address in 1899 as representing a total income for that year of $120.00, show that during the past year the income was not less than $6019.54; and that with the increase of membership following the present convention the society should be free in future from all obligations or pecuniary cares. The publication also shows what the Society is doing in the making of specifications, and with what intelligence and scientific authority its members deal with the subject presented in their papers.

OUR SPECIFICATIONS AND COOPERATION WITH SISTER SOCIETIES.

The growth of our organization as a clearing house for the specifications of the scientfic societies of the United States has been marked. No steps in the preparation of specifications and the adoption of methods for manipulation of tests are proposed in any of the scientific societies to-day without the suggestion of the cooperation in the same by this body. This sentiment of cooperation among the national scientific societies is one of the best evidences of scientific development of the American mind and of the desire to procure in the most compact form the condensed thought of the greatest number of intelligent minds, familiar with dealing with the subject brought up. It is this cooperation which has led to the successful promulgation by our Society of no less than eighteen specifications during the past five years. It is this cooperation which has tended to make our Society recognized as one of the leading ones in the United States, and one most devoted to work and most fruitful in results. This coop-

eration in a single industrial development, that of Concrete and Reinforced Concrete, will have much to do with the forming of proper specifications for legislation in all the large cities of the country, covering the construction of Concrete and Reinforced Concrete. Further recognition of your Society as a scientific body is shown by the appointment by President Roosevelt of your President and Vice-President, as members of the United States Advisory Board on Structural Materials and Fuels, a board composed of the leading scientific societies of the United States, and of the heads and representatives of the Army, Navy, the Panama Canal Commission, the Geological Survey, and other important branches of the Government. Recognition was more marked in the case of our body than any other scientific body in the selection of our President Dudley, as President of the Advisory Board.

The eighteen specifications adopted, representing the concensus of opinion of producers, consumers, engineers, and various scientific and industrial associations, are as follows:

1. Standard Specifications for Structural Steel for Bridges.
2. Standard Specifications for Structural Steel for Ships.
3. Standard Specifications for Structural Steel for Buildings.
4. Standard Specifications for Open Hearth Boiler Plate and Rivet Steel.
5. Standard Specifications for Steel Rails.
6. Standard Specifications for Steel Splice Bars.
7. Standard Specifications for Steel Axles.
8. Standard Specifications for Steel Tires.
9. Standard Specifications for Steel Forgings.
10. Standard Specifications for Steel Castings.
11. Standard Specifications for Wrought Iron.
12. Standard Specifications for Foundry Pig Iron.
13. Standard Specifications for Cast Iron Pipe and Special Castings.
14. Standard Specifications for Locomotive Cylinders.
15. Standard Specifications for Cast Iron Car Wheels.
16. Standard Specifications for Malleable Castings.
17. Standard Specifications for Gray Iron Castings.
18. Standard Specifications for Cement.

There are committees at work on additional specifications, and it is expected that at the present meeting reports from several of the following will be presented for action.

Committee D on Standard Specifications and Tests for Paving and Building Brick.

Committee H on Standard Specifications and Tests for Road Materials.

Committee J on Standard Specifications for Foundry Coke.

Committee K on Standard Methods of Testing.

Committee L on Standard Specifications and Tests for Clay and Cement Sewer Pipes.

Committee M on Standard Specifications for Staybolts.

Committee N on Standard Tests for Lubricants.

Committee Q on Standard Specifications for the Grading of Structural Timber.

Committees R on Uniform Specifications for Boilers.

Committees T on the Tempering and Testing of Steel Springs and Standard Specifications for Spring Steel.

Committee U on Standard Specifications and Tests for Wire Rope.

The Committees which have already reported specifications are still in existence, and it is the policy of the Society to keep all its committees as standing committees, ready at any time to change or modify specifications, in accordance with the changes that may be made.

The value and general use of these specifications as governing buyer and seller in the handling of commercial products may well be illustrated in the case of the Cement specifications, which may be said to have been generally adopted in the trade, and of which no less than 25,000 copies have been distributed, mostly on request.

The international character of our work is especially recognized in the report of the British Standard Specifications Committee, who, in their report, commend the specifications produced by the American Society, and express the hope that they might, together with those of the British Standards Committee, form the basis for international specifications the world over.

SCIENTIFIC SIDE.

A perusal of the volumes of Proceedings of the Society for Testing Materials is like reading the index to the biography of the distinguished men in the various branches represented in our body. In the field of iron, steel, and other metals, papers of the greatest importance to the scientific world, have been read by Campbell, Colby, Job, Metcalf, Richards, Sauveur, and many others, and the names on the committees on specifications in these branches are of distinction in manufacturing, engineering, and testing science. So too, in the field of cement, asphalt, and bitumen, Dow, Humphrey, Lazell, McKenna, Richardson, Talbot, Taylor, and others, have contributed papers of the greatest value, and in the field of preservative coatings for iron and steel excellent papers have been presented by Barker, Job, Thompson, and others. But more to the purpose and more in the special field of our Society, and greater in your renown, are those papers presented in the form of annual addresses by our former Presidents, Professors Howe and Merriman, and by our present President, Dr. Dudley. These papers should certainly be made the subject of a special volume directed specifically to the advantages of testing. Professor Howe's philosophical address at the June, 1902, convention at Atlantic City—his clear analysis of the purposes of a society devoted to the testing of materials—forms a little epitome of the subject so crisp and so clear that no one having to do with testing should be without it, nor should anyone having to do with testing, neglect to read the few brief remarks that Professor Howe delivered in his annual address at Buffalo. As for our worthy President, Dr. Dudley's three masterly addresses at the sixth, seventh, and eighth Annual Conventions—they are replete with deep thought, clear insight, and philosophical analysis and yet are full of common sense and actual facts, and in themselves form almost a compendium of the literature of testing. Supplement this with Professor Lanza's brief review of "Testing in the United States," his "Memoirs of Deceased American Investigators," and Professor Hatt's "Course of Laboratory Instruction in Testing Materials," and bind all these addresses together in a single volume, there is at the hand of every testing engineer in this country and any other country, a mass of well-digested, well-sketched, well-expressed literature that he cannot afford to be without.

In considering the presentation of all these papers before our Society, covering such a wide field of knowledge and science and representing so much hard work on the part of members, it would appear that our organization offers a special field to the clever man, and especially to the rising man in any branch of industry. It is not a society of engineers listening to engineers; it is not a society of doctors listening to doctors; it is not a society of lawyers listening to lawyers; but it is a society of engineers, testing engineers, manufacturers, and large producers listening to those who have a message to carry in their chosen field. It is from the ranks of those rising men and those intelligent men who read papers before our Society that the great captains of industry of the future are coming; and it is they who will rule the industries of the United States in the next generation. Their ability, industry, and other qualities, recognized in the meetings of our Society by those who have use for just such talents, will be productive of the greatest good to all the industries forming our membership and to the country at large.

THE FUTURE.

If the future is to be judged by the past, our Society should become one of the strongest in membership and the most vigorous in intellectual development of any in this country. The "Engineering News," in commenting upon our annual convention in 1905, well says:

> That this new society came into being as the successor of the previous branch organization is a minor detail; the need for the new society was independent of the existence of the other organization, and the latter merely served as a scaffolding for the erection of the other. Science and art in testing in America seem to be an essential adjunct to both manufacturing and construction, and in correspondence, the testing engineers have increased in number until they have come into a recognized position among engineering specialists. There was need then of an organization which would bring these engineers together for the discussion of their common problems and for their joint action and mutual benefit. This Society fills that position and has come to stay as the development of the American idea in the making and standardizing of specifications.

At the Atlantic City convention in 1902, Professor Howe says:

It is well that there should be some society with this as its chief object. It should represent both sides of the negotiations, seller and buyer, maker and user. It should represent also what we term their professional counsel, the consulting and inspecting engineers. If I may still further borrow the terms of litigation, it should represent also the bench, that is to say, the institutions of learning through their teaching and investigating staff and engineering press. These three classes should be fully represented in our membership and our Executive Committee.

This practical and clear-cut view of our purposes should never be lost sight of, but we might carry the projected rainbow of the bench or judicial side of our Society to earth and make the form complete by providing at some time some great central testing laboratory under the auspices of this Society, either with the cooperation of the United States Government and its Advisory Board, or as a separate institution of our Society, to act in this judicial capacity referred to in Professor Howe's address. In view of the great gifts to colleges and institutions of learning by the rich men of this country; in view of the gifts of the great iron master, Andrew Carnegie, to engineering societies and other kindred bodies; in view of the homely feeling of the successful manufacturer in any great industry to put back in the soil by gifts to educational institutions, technical schools, hospitals or charities for the workingmen, that which he has taken from it, what better use for such gifts could be found than the development under the auspices of a testing society of a great testing laboratory for all the materials covered by the great industries of our country? Such an institution should be one not devoted merely to commercial testing, not competing with organized testing laboratories, but it should be rather a supreme court of testing, to which the public would look for the final decision after the case has been argued in the lower courts, and whose conclusion supported by the reputation, the intelligence, and the ability represented in this body, would be positive, definite and final.

REPORT OF COMMITTEE A ON STANDARD SPECIFICATIONS FOR IRON AND STEEL.

At the last annual meeting Committee A recommended the adoption under the title "Standard Specifications for Steel Rails" the specifications adopted by the American Railway Engineering and Maintenance of Way Association, based originally on our own specifications, subject to certain changes indicated in the report.

The recommendations of the Committee were adopted at the last annual meeting with the following exceptions:

1. That the proposed change in clause 3 of "from each blow" to "from every fifth blow" be referred back to the Committee for further information.
2. That the words "taken from the top of the ingot" be inserted in clause 3 after the words "if any rail break when subject to the drop test, two additional tests."
3. That clauses 4, 7 and 8 be referred to Committee A with power to act.

The foregoing instructions to the Committee were subsequently enlarged by instructions from the Executive Committee to include the consideration of action taken by other leading societies on matters pertaining to specifications for Steel Rails and Bridge Material and that the report of the Committee at the annual meeting of the Society be drawn so as to embody the reasons for and against the more important remaining points of difference between the standard specifications of the Society in their present or proposed modified form, and those adopted or proposed by other societies or their committees.

The Executive Committee further called the attention of our Committee to the desirability of bringing up the subject of Standard Specifications for Ship Material for a general discussion at the next annual meeting.

Committee A held a meeting of four sessions on May 3-4, 1906, with a view of taking action on the above matters. This meeting was attended by eighteen of the thirty-nine members of the Committee.

The results of this meeting may be briefly summarized as follows:

I. ON SPECIFICATION FOR STEEL RAILS.

(a) Action on matters referred to the Committee at last annual meeting.

Clause 3. Previous recommendation that the requirement of a drop test in the specifications of the American Railway Engineering and Maintenance of Way Association. "From each blow" be changed to "from every fifth blow" reaffirmed.

Clause 4. It was decided to recommend the adoption of the following modified form:

Original Form.

The number of passes and speed of train shall be so regulated that on leaving the rolls at the final pass the temperature of the rail will not exceed that which requires a shrinkage allowance at the hot-saws of 6 in. for 85-pound and 6⅛ in. for 100-pound rails, and no artificial means of cooling the rails shall be used between the finishing pass and the hot-saws. The above shrinkage allowance may be varied, if necessary, so as to give a finishing temperature of not exceeding 1,600 degrees Fahrenheit at finishing rolls for mills rolling from reheated blooms, and not exceeding 1,750 degrees Fahrenheit at finishing rolls for mills rolling direct from the bloom to finished rail.

Proposed Modified Form:

The number of passes and speed of train shall be so regulated that on leaving the rolls at the final pass, the temperature of the rail will not exceed that which requires a shrinkage allowance at the hot-saws, for a 30-ft. rail of 100 lb. section, of $6\frac{1}{16}''$ and $\frac{1}{16}''$ less for each 5 lb. decrease of section. These allowances to be decreased at the rate of .01″ for each second of time elapsed between the rail leaving the finishing rolls and being sawn. No artificial means of cooling the rails shall be used between the finishing pass and the hot-saws.

Clauses 7 and 8. It is recommended that these clauses, quoted below, be adopted after amending clause 7 by striking out the last sentence, "The section of rail shall conform perfectly to the finishing dimension," this provision being inconsistent with other requirements in these clauses.

(7) Unless otherwise specified, the section of rail shall be the American Standard, recommended by the American Society of Civil Engineers,

and shall conform, as accurately as possible, to the templet furnished by the railroad company, consistent with paragraph No. 8, relative to specified weight. A variation in height of one sixty-fourth (1-64) of an inch less, or one thirty-second (1-32) of an inch greater than the specified height, and one-sixteenth (1-16) inch in width will be permitted. The section of rail shall conform perfectly to the finishing dimension.

(8) The weight of the rails will be maintained as nearly as possible, after complying with paragraph No. 7, to that specified in contract. A variation of one-half (½) of one per cent. for an entire order will be allowed. Rails shall be accepted and paid for according to actual weights.

(b) Comparison of the principal features in the standard specifications of the American Society for Testing Materials and in the specifications proposed by the Special Committee on Rail Sections of the American Society of Civil Engineers, and the revised specifications of the American Railway Engineering and Maintenance of Way Association.

DISCARD.

American Society for Testing Materials:

Sufficient material shall be sheared from the top of ingot to insure sound rails.

American Society of Civil Engineers:

There shall be sheared from the end of the blooms formed from the top of the ingots, assuming that such blooms are about 8 by 8 in. square, at least 40 inches, and if, from any cause, the steel does not then appear to be solid, the shearing shall continue until it does. If, by the use of any improvements in the process of making ingots, the defect known as piping shall be prevented, the above shearing requirements may be modified.

American Railway Engineering and Maintenance of Way Association:

There shall be sheared from the end of the blooms formed from the top of the ingots not less than twenty-five per cent, and if, from any cause, the steel does not then appear to be solid, the shearing shall continue until it does. If, by the use of any improvements in the process of making ingots, the defect known as piping shall be prevented, the above shearing requirements may be modified.

A motion to specify some definite minimum percentage of discard was lost, and the existing clause in the standard specifications was reaffirmed.

CHEMICAL COMPOSITION.

American Society for Testing Materials:

Rails of the various weights per yard specified below shall conform to the following limits in chemical composition:

	per cent				
	50 to 59 lbs.	60 to 69 lbs.	70 to 79 lbs.	80 to 89 lbs.	90 to 100 lbs
Carbon	0.35–0.45	0.38–0.48	0.40–0.50	0.43–0.53	0.45–0.55
Phosphorus not to exceed	0.10	0.10	0.10	0.10	0.10
Silicon shall not exceed	0.20	0.20	0.20	0.20	0.20
Manganese	0.70–1.00	0.70–1.00	0.75–1.05	0.80–1.10	0.80–1.10

American Society of Civil Engineers:

Chemical Composition.—Rails of the various weights per yard specified below shall conform to the following limits in chemical composition:

	70 to 79 lbs. percentage.	80 to 89 lbs. percentage.	90 to 100 lbs. percentage.
Carbon	0.50–0.60	0.53–0.63	0.55–0.65
Phosphorus shall not exceed	0.085	0.085	0.085
Silicon shall not exceed	0.20	0.20	0.20
Sulphur shall not exceed	0.075	0.075	0.075
Manganese	0.75–1.00	0.80–1.05	0.80–1.05

American Railway Engineering and Maintenance of Way Association:

Same as above with the following footnote: "Carbon may be reduced to suit local conditions."

It was decided to recommend that the present requirements as to chemical composition be retained.

STRAIGHTENING.

American Society for Testing Materials:

Rails shall be straight when finished, the straightening being done while cold, smooth on head, sawed square at ends, variation to be not over one thirty-second ($\frac{1}{32}$) of an inch, and prior to shipment shall have the burr occasioned by the saw cutting removed and the ends made clean. No. 1 rails shall be free from injurious defects and flaws of all kinds.

American Society of Civil Engineers:

Straightening.—Care must be taken in hot-straightening the rails, and it must result in their being left in such a condition that they shall

not vary throughout their entire length more than 5 inches from a straight line in any direction, when delivered to the cold-straightening presses. Those which vary beyond that amount, or have short kinks, shall be classed as second-quality rails and be so stamped.

Rails shall be straight in line and surface when finished—the straightening being done while cold—smooth on head, sawed square at ends, variation to be not more than $\frac{1}{32}$ inch, and, prior to shipment, shall have the burr occasioned by the saw cutting removed, and the ends made clean. No. 1 rails shall be free from injurious defects and flaws of all kinds.

American Railway Engineering and Maintenance of Way Association:

Straightening.—Care must be taken in hot straightening the rails, and it must result in their being left in such a condition that they shall not vary throughout their entire length of 33 feet more than 3 inches from a straight line in any direction, when delivered to the cold straightening presses. Those which vary beyond that amount, or have short kinks, shall be classed as second quality rails and be so stamped. The distance between supports of rails in the gagging press shall be not less than 42 inches.

Rails shall be straight in line and surface when finished—the straightening being done while cold—smooth on head, sawed square at ends, variation to be not more than $\frac{1}{32}$ inch, and, prior to shipment, shall have the burr occasioned by the saw cutting removed, and the ends made clean. No. 1 rails shall be free from injurious defects and flaws of all kinds.

It was decided not to recommend the introduction of a requirement as to permissible camber of rails nor any other change.

II. ON SPECIFICATIONS FOR BRIDGE MATERIAL.

The following changes recently adopted by the American Railway Engineering and Maintenance of Way Association were discussed and it was decided to report adversely on each of these points:

(a) Elongation in steel casting specimens changed from 18 per cent. to 15 per cent.

(b) Phosphorous limit in acid structural steel changed from .08 to .06.

(c) The change of "a retest may be made" to "a retest shall be made."

It was decided to make no change in the following matters

referred to the Committee of the American Railway Engineering and Maintenance of Way Association for investigation:

(d) Changing phosphorus content in steel castings from .05 for basic and .08 for acid, to .06.
(e) Raising the desired ultimate of structural steel from 60,000 to 62,000 pounds.

On motion a sub-committee consisting of Messrs. George E. Thackray (chairman), W. A. Bostwick, P. E. Carhart and E. F. Kenney, was appointed to draw up a report setting forth the reasons for and against the foregoing points of difference with a view of presenting the report at a meeting of the Committee to be held in advance of the Annual Meeting.

This sub-committee presented the following report:

REPORT OF SUB-COMMITTEE.

This sub-committee presented a report at a meeting of Committee A on June 20, 1906, attended by fourteen of thirty-nine members of the Committee, which, after full discussion, was adopted in the following amended form:

DROP TEST.

It is thought that the change from a test "from every fifth blow" to "from each blow" should not be made because (1) the specifications in their proposed modified form provide that the test shall hereafter be taken from the top of the ingot, and (2) that such a requirement in a general specification would impede the work of the mills unnecessarily.

SHRINKAGE CLAUSE.

The following reasons for and against the proposed modified form of this clause are offered:

FOR.—Because service conditions in the track do not indicate that greater shrinkage produces poorer wearing rails than rails manufactured under a shrinkage requirement of one (1) inch less than that proposed. Further, the resulting decrease of output at two-thirds of the mills in the country renders it prohibitive to

adopt the lower shrinkage requirement, proposed in the other specifications.

AGAINST.—It is generally admitted that colder finishing of steel at or near the critical temperature results in betterment of the structure. A number of experiments on rails in track rolled at lower temperatures, but similar in other respects, have almost invariably shown better wearing qualities.

DISCARD.

The reasons for and against the existing clause governing Discard may be stated as follows:

FOR.—On account of the essential and necessary variations in practice at different mills, and the fact that even under the best conditions in any one mill, the unsoundness, if any, at the top of an ingot will vary; therefore a specification requiring "a sufficient discard" is better than one requiring a fixed amount of discard.

AGAINST.—The number of breakages in rail has shown that the word "sufficient," as at present interpreted, does not guard against brittle rails going into the tracks. The process of shearing should be as much a subject for inspection as any other part of rail-mill practice, and a definite specification which will give the inspector some guide is necessary. While a fixed percentage of discard may cause the loss of some good material, it is reasonably certain to insure the elimination of most of the bad.

The word "sufficient" is interpreted by the mills as sufficient from their point of view, and the inspector who represents the consumer at the mills is allowed no say in the matter. Moreover in making steel for other purposes, such as axles, eye-bars, etc., a heavy discard is made to insure good material, whereas the stresses and shock to which a rail is subjected are much greater than in the case of an axle or an eye-bar.

CHEMICAL COMPOSITION.

The reasons for and against adherenee to the present specifications governing chemical compositions may be stated as follows:

FOR.—While it is conceded that less phosphorus may be better in general, we are met in this case by the practical impossibility of reducing the percentage of this metalloid in connection

with the Bessemer process, for the reason that a sufficient supply of low-phosphorus ore for producing the required large tonnage of rails is not available. As between 0.10 and 0.085 phosphorus the advantage of the lower amount is questionable, some results from rails made under the lower requirement having been unsatisfactory.

Considering that it is desirable to take the drop test from the top of ingot, the present percentage of carbon should be maintained as consistent with the heights of drops specified. The percentages of carbon may be increased provided suitable reductions in heights of drop test be made.

AGAINST.—Phosphorus is universally admitted to be an unmixed evil in steel, and the lower we can keep its percentage the more use we can make of proper hardeners, thereby adding to the wearing qualities of rails without the danger of brittleness caused by higher phosphorus. With an allowable percentage of 0.10 for phosphorus, we do not dare to make rails hard enough to wear well.

STRAIGHTENING.

The reasons for and against the omission of a definite requirement for permissible camber may be stated as follows:

FOR.—Since the camber in rails depends largely upon the distribution of the metal in the section, it is manifestly impossible to stipulate a maximum amount covering all sections. Further, since all mills aim to deliver rails as straight as possible to the gag presses in order to insure greater output, it seems unfair to penalize them on occasions when it is found impossible to control this.

AGAINST.—In many mills the rails come to the straightening presses in all conditions from nearly straight to very badly cambered. In the case of a badly cambered rail, the first operation in straightening is to hit it with the gag at intervals of about 18 inches throughout its length. When it is considered that the material is thus strained beyond the elastic limit at each blow, the necessity of reducing this gagging to a minimum becomes quite apparent. Excessive gagging often causes a crack in the rail, and rails which have been subjected to the same should be treated like rails defective in other respects, that is as "second quality." This will insure their being laid in places where they will not be required to

stand the most severe service. Such rails should be marked as "Number twos" before straightening, as it is almost impossible to detect after straightening the rails which were too severely gagged. That specifications fixing the allowable limit of camber can be complied with, is evident from the fact that some mills meet the proposed specifications in their present practice.

In the discussion of the above report, Mr. A. J. Colby called attention to the desirability of modifying Clause 3 in harmony with the specifications prepared by Mr. C. S. Churchill for The Norfolk and Western Railroad, by which "a drop test *may* be taken from *each* blow of steel, and *shall* be taken for every *fifth* blow," which would provide for additional tests in case the results from the tests of every fifth blow prove unsatisfactory.

Respectfully submitted on behalf of the Committee,

W. R. WEBSTER,
Chairman.

EDGAR MARBURG,
Secretary.

APPENDIX.

PROPOSED STANDARD SPECIFICATIONS FOR STEEL RAILS.

Process of Manufacture.

(1) (a) The entire process of manufacture and testing shall be in accordance with the best current practice, and special care shall be taken to conform to the following instructions:

(b) Ingots shall be kept in a vertical position in the pit heating furnaces until ready to be rolled, or until the metal in the interior has time to solidify.

(c) No bled ingots shall be used.

(d) Sufficient material shall be discarded from the top of ingot to insure sound rails.

Chemical Composition.

(2) Rails of the various weights per yard specified below shall conform to the following limits in chemical composition:

	50 to 59 Pounds. Per cent.	60 to 69 Pounds. Per cent.	70 to 79 Pounds. Per cent.	80 to 89 Pounds. Per cent.	90 to 100 Pounds. Per cent.
Carbon	0.35-0.45	0.38-0.48	0.40-0.50	0.43-0.53	0.45-0.55
Phosphorus, shall not exceed	0.10	0.10	0.10	0.10	0.10
Silicon, shall not exceed	0.20	0.20	0.20	0.20	0.20
Manganese	0.70-1.00	0.70-1.00	0.75-1.05	0.80-1.10	0.80-1.10

Drop Test (one from each heat).

(3) One drop test shall be made on a piece of rail not less than four feet and not more than six feet long, selected from every fifth blow of steel. The test shall be taken from the top of the ingot. The rail shall be placed head upwards on the supports, and the various sections shall be subjected to the following impact tests under a free falling weight:

	Weight of Rail. Pounds Per Yard.	Height of Drop Feet.
	45 to and including 55	15
More than	55 " 65	16
More than	65 " 75	17
More than	75 " 85	18
More than	85 " 100	19

If any rail break when subject to the drop test, two additional tests taken from the top of the ingot will be made of other rails from the same blow of steel, and if either of these latter tests fail,

all the rails of the blow which they represent will be rejected, but if both of these additional test pieces meet the requirements, all the rails of the blow which they represent will be accepted.

Finishing Temperature. (4) The number of passes and speed of train shall be so regulated that on leaving the rolls at the final pass the temperature of the rail will not exceed that which requires a shrinkage allowance at the hot-saws, for a 30 foot rail of 100 lb. section, of $6\frac{1}{16}$", and $\frac{1}{16}$" less for each 5 lb. decrease of section. These allowances to be decreased at the rate of .01" for each second of time elapsed between the rail leaving the finishing rolls and being sawn. No artificial means of cooling the rails shall be used between the finishing pass and the hot-saws.

Drop Testing Machine. (5) The drop testing machine shall have a tup of two thousand (2,000) pounds weight, the striking face of which shall have a radius of not more than five (5) inches, and the test rail shall be placed head upwards on solid supports three (3) feet apart. The anvil block shall weigh at least twenty thousand (20,000) pounds, and the supports shall be part of, or firmly secured to, the anvil. The report of the drop test shall state the atmospheric temperature at the time the test was made.

Chemical Analyses. (6) The manufacturer shall furnish the inspector, daily, with carbon determinations for each blow, and a complete chemical analysis every twenty-four hours, representing the average of the other elements contained in the steel, for each day and night turn. These analyses shall be made on drillings taken from small test ingot.

Section. (7) Unless otherwise specified, the section of rail shall be the American Standard, recommended by the American Society of Civil Engineers, and shall conform, as accurately as possible, to the templet furnished by the railroad company, consistent with paragraph No. 8, relative to specified weight. A variation in height of one-sixty-fourth (1-64) of an inch less, or one thirty-second (1-32) of an inch greater than the specified height, and one-sixteenth (1-16) inch in width will be permitted.

Weight. (8) The weight of the rails will be maintained as nearly as possible, after complying with paragraph No. 7, to that specified in contract. A variation of one-half ($\frac{1}{2}$) of one per cent. for an entire order will be allowed. Rails shall be accepted and paid for according to actual weights.

Length. (9) The standard length of rails shall be thirty (30)

feet. Ten per cent. of the entire order will be accepted in shorter lengths, varying by even feet to twenty-four (24) feet, and all No. 1 rails less than 30 feet shall be painted green on the end. A variation of one-fourth of an inch in length from that specified will be allowed.

Drilling.

(10) Circular holes for splice bars shall be drilled in accordance with the specifications of the purchaser. The holes shall accurately conform to the drawing and dimensions furnished in every respect, and must be free from burrs.

Finish.

(11) Rails shall be straight when finished, the straightening being done while cold, smooth on head, sawed square at ends, variation to be not over one-thirty-second (1-32) of an inch, and prior to shipment shall have the burr occasioned by the saw cutting removed and the ends made clean. No. 1 rails shall be free from injurious defects and flaws of all kinds.

Branding.

(12) The name of the maker, the weight of rail and the month and year of manufacture shall be rolled in raised letters on the side of the web, and the number of blow shall be plainly stamped on each rail where it will not subsequently be covered by the splice bars.

Inspection.

(13) The inspector representing the purchaser shall have free entry to the works of the manufacturer at all times when the contract is being filled, and shall have all reasonable facilities afforded him by the manufacturer to satisfy him that the finished material is furnished in accordance with the terms of these specifications. All tests and inspection shall be made at the place of manufacture prior to shipment.

No 2 Rails.

(14) No. 2 rails will be accepted up to ten (10) per cent. of the whole order. Rails that possess any injurious defects, or which for any other cause are not suitable for first quality, or No. 1 rails, shall be considered as No. 2 rails; provided, however, that rails which contain any physical defects which impair their strength shall be rejected. The ends of all No. 2 rails shall be painted white in order to distinguish them.

REPORT OF COMMITTEE B ON STANDARD SPECIFICATIONS FOR CAST IRON AND FINISHED CASTINGS.

The Chairman of Committee B has communicated with each of the chairmen of the sub-committees, who reported that no changes were to be suggested in the specifications that had been prepared, and that nothing had come up in the past year which called for comment.

The chairman of the sub-committee on Cast Iron Pipe reported that the American Water Works Association had up for discussion at their last annual meeting the propriety of their Association framing specifications for cast iron pipe. The subject was referred to a committee by the Convention. There have been several conferences between this Committee and the sub-committee of Committee B as to the various suggestions that have been proposed. No final result, however, has been reached.

Should definite action be taken by the American Water Works Association at their convention next month, the Chairman of the Sub-Committee on Cast Iron Pipe desires to have the authority of the Society to continue discussions with the American Water Works Association,* and to see how far any differences in specifications can be adjusted, so that there may be a specification framed which shall meet with the approval of the various engineering societies interested.

Respectfully submitted on behalf of the Committee,

WALTER WOOD,
Chairman.

RICHARD MOLDENKE,
Secretary.

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* On motion Committee B was authorized to confer with the committees on Specifications for Cast Iron Pipe of the American Water Works Association with a view of harmonizing results.—ED.

REPORT OF COMMITTEE E ON PRESERVATIVE COATINGS FOR IRON AND STEEL.

As stated in the last report of this Committee, the work of clearing the ground during the past three years has prepared the way for such a series of practical tests as are now reported. The plan followed during the past year of specializing the work of the general Committee by sub-committees will hasten the final solution of the problem materially. The report and recommendations of sub-committee on Field and Service Tests presented in the annual report of last year has been the basis of the following tests:

The structure placed at the disposal of the Committee is a part of the new double-track deck bridge erected by the Pennsylvania Railroad Company at Havre de Grace. This bridge consists of 17 fixed spans, including two 192 ft., seven 195 ft. 5 in., and eight 255 ft., center to center of end pins, and one draw span, 277 ft. 2 in., center to center of end pins. The trusses are about 30 feet deep and the panels 29 feet long. The entire bridge contains some 21,000,000 pounds of steel.

A through bridge would perhaps have offered, in some respects, more favorable conditions for the test, as the effect of smoke and gases from the locomotives could have been noted on the overhead parts of the structure, and ease of inspection would have been increased. These objections are, however, not vital, while the advantages will be practically uniform conditions throughout the entire length of the bridge, severe atmospheric conditions, and permanence of the structure.

The Society having no funds for such a series of tests, paint manufacturers were requested to aid the Committee by donations of funds for the preparation of surface and application of paint, and also to supply the paint they desired to have tested.

To bring the test to their attention, the following circular was issued:

WASHINGTON, D. C., January 31, 1906.

Dear Sirs:–

The Pennsylvania R. R. Co. have kindly placed at the disposal of Committee E of the American Society for Testing Materials a

whole or a part of their new bridge at Havre de Grace, Md., for the purpose of making extensive field tests of preservative coatings.

It is the purpose of this communication to give such information as to the details of the proposed test as to enable each manufacturer to determine whether or not he will enter.

The membership of Committee E is as follows:

S. S. Voorhees, Engineer of Tests, Supervising Architect's Office, U. S. Treasury Department, Washington, D. C., Chairman.

CONSUMERS.

Dr. C. B. Dudley, Chemist, Pennsylvania R. R., Altoona, Pa.
Mr. W. A. Aiken, 613 Empire Building, Pittsburg, Pa.
Mr. Robt. Job, Chemist, Philadelphia and Reading Ry., Reading, Pa.
Mr. A. W. Dow, Washington, D. C.
Mr. Max Wickhorst, Engineer of Tests, Chicago, Burlington and Quincy R. R., Aurora, Ill.
Mr. L. H. Barker, Pennsylvania R. R., Jersey City, N. J.
Mr. Wirt Tassin, Washington, D. C.
Mr. Wm. R. Webster, 411 Walnut St., Philadelphia, Pa.
Mr. James Christie, Chief Mechanical Engineer, American Bridge Co., Pencoyd, Pa.
Mr. McIlheney, New York City.
Mr. J. R. Onderdonk, Engineer of Tests, Baltimore and Ohio R. R., Mt. Clair, Baltimore, Md.
Mr. George Heckel, 636 Bourse Building, Philadelphia, Pa.

PRODUCERS.

Mr. Malcolm McNaughton, Jersey City, N. J.
Mr. C. O. Collins, Niagara Falls, N. Y.
Mr. Spencer Newberry, Sandusky, Ohio.
Mr. W. A. Polk, 42 Hudson St., New York City.
Mr. A. H. Sabin, 432 Sanford Ave, Flushing, L. I., N. Y
Mr. G. W. Thompson, 129 York St., Brooklyn, N. Y.
Mr. J. W. Whitehead, Jr., 1 Madison Ave., New York City
Mr. C. N. Forrest, Long Island City, N. Y.
Mr. J. F. Walker, Bridgeport, Pa.
Mr. Chas. J. Davies, Reading, Pa.

It is the policy of the American Society for Testing Materials to maintain a proper balance in all committees of the Society between the producers and the consumers, the chairman of the general committee, however, is an engineer or a consumer, so that the chairman will have the deciding voice.

The structure at our disposal is a double-track deck bridge, the trusses of which are about thirty feet deep and each panel about twenty-nine feet long. It is proposed that an entire cross section of this bridge,

about twenty feet wide, double track—one or two panels in length—be assigned for each test, excepting the floor system which has been painted. The painting is to be done as soon as settled spring weather is reached in April and May.

In addition to the field tests above mentioned, there will be an auxiliary service test as follows:

It is proposed to paint a number of panels of sheet steel carefully prepared so as to secure uniformity of conditions with the various paints to be used, these paints are to be exposed alongside of the particular paint sections to which they correspond. The proposition is to have nine plates painted with each paint, three of these to be spread out at one uniform rate, a second three spread at another uniform rate, and the remaining three spread at a third uniform rate—three coats—the rates being, say 600, 900, and 1,200 square feet per gallon for oil paints and 300, 600, and 900 square feet for paints containing much volatile thinner. The work will of necessity be conducted under the close supervision of a Director of Tests. The United States Steel Corporation has promised to contribute the plates for these tests free of charge.

The estimated expenses of this trial, including the preparation of the surface, application of three coats of paint the services of a Director of Tests and helpers, analyses of the samples in duplicate, cost of distribution and storage of material, etc., will be as follows: Paint, cleaning and application, $3.00 per running foot; the salary of a Director of Tests and helpers, $500.00; workshop and storage room, $1,000.00, and analyses of paint per sample, $20.00.

On this assumption, based on participation by varying numbers of manufacturers, the following table is approximated:

Manufacturers:	50.	40.	30.	20.
30 feet	$160.00	$167.50	$180.00	$205.00
60 feet	252.50	260.00	274.00	300.00

The estimate of $1,000.00 for store-shed and workshop will be reduced several hundred dollars if cars are secured for this purpose. The amount of paint required is estimated at from fifty to seventy-five gallons per panel of thirty feet long. The committee feels confident that the figures given will considerably more than cover the expenses of the test.

The manufacturers are expected to give a description of their paint for classification purposes, and are further requested to give detailed instruction in regard to the best method of applying the paint; and the director of tests will see that these instructions are observed. The surface of the metal will be mechanically cleaned with hammers, steel scrapers and wire brushes, so that all detachable mill scale, rust and dirt are removed; any oil and grease will be removed by benzine.

The Society has no fund available for this trial, and it will be necessary for the manufacturers to make a deposit sufficient to cover their share of the expenses. Any unused portion will be refunded.

A Director of Tests shall be appointed by Committee E. The details of conducting the test are to be determined by Committee E, and so framed as to be eminently fair to each competitor and to the paints themselves. The steel is now covered by a shop coat of linseed oil. Before the application of any paint this will be cleaned off as thoroughly as possible. The Director of Tests shall determine when the surfaces are sufficiently cleaned.

The paint shall not be applied in rainy or foggy weather, or when the humidity exceeds average conditions.

The Committee hopes that the information given is full enough to enable the manufacturers to decide on the advisability of entering this trial.

Will you please give this matter your immediate attention, and inform me at your earliest convenience if you desire to aid the Committee in this matter?

Very truly yours,
S. S. VOORHEES.

Replies from some 20 paint manufacturers were received in response to this circular, stating their willingness to aid the Committee to the extent desired. Accordingly the question of cost was figured out on the basis of 20 panels of 30 feet each, and a set of questions was framed covering composition of paint, etc., as embodied in the following letter:

Gentlemen:

You are advised that the paint test to be made on the Pennsylvania Railroad bridge over the Susquehanna River at Havre de Grace will be started immediately. Some twenty paint manufacturers have signified their intention of aiding the Committee in these tests.

It has been decided that each paint will be allowed one panel, practically 30 ft., but if a manufacturer desires to submit more than one paint or expose more than one panel, additional space on the above unit basis will be assigned them.

It has also been decided that the surface shall be uniformly cleaned with wire brushes, scrapers and hammers; oil and grease to be removed with benzine.

It has further been decided that either two or three coats shall be applied as desired by the manufacturer. There is no color restriction for under coats, but final coat must be black, dark brown, dark drab, or some neutral color.

The panels used for these tests will be entirely over water and will extend continuously north from draw.

The actual space allotted to each paint will be determined by lot.

The results obtained by this investigation of the American Society for Testing Materials are intended to be of scientific value to the engineer

and to aid manufacturers in producing paint which will meet certain conditions and are not to advertise any particular brand of paint. With this in mind, the following series of questions have been framed by the Committee so as to enable them to classify the paints used in these tests:

Character, composition, and description of the paint for the purpose of classification and the general information of the Committee; also such other information as the producer is willing to have published.

Information is desired under the following heads, giving at least the commercial name, and the proportion, amount or percentage of each ingredient:

A. Pigment.
B. Volatile thinner.
C. Vehicle or liquid non-volatile matter.
   Particular information is desired as to the following:
   (1) Saponifiable oils, *i. e.* linseed, etc.
   (2) Resinous matters, *i. e.* rosin and gums.
   (3) Bituminous matters, *i. e.* asphaltum, pitch, etc.
   (4) Non-saponifiable oils, as petroleum, rosin oil, etc.
D. Mineral matter such as lead, manganese, lime, etc., other than that present as pigment.

This information is not intended to include trade secrets or particular methods of treatment or manufacture of the constituents.

Further you will please furnish the Committee with detailed information as to the manner in which you recommend that your paint should be applied, it being understood that unless you supply special brushes, a standard round brush will be used.

Finally you will kindly inform the Committee at what price you would be prepared to supply the paint submitted, under present market conditions.

Will you please answer these questions as fully as possible and return to chairman of Committee, together with check for $205 (per panel of 30 ft.), made out to Joseph F. Walker, Secretary of Committee. The unused portion of this sum will be refunded.

Work will be started immediately and instructions as to shipping will be sent shortly.

Yours truly,
S. S. VOORHEES,
Chairman.

The replies to the circular letter were to be used by the Committee, as stated, in classifying paints submitted.

Unfortunately these questions on composition were regarded as too searching by many paint manufacturers on the ground that if answered they would disclose trade secrets and methods of manufacture. As the tests were seriously jeopardized by these questions they were withdrawn and only such information

requested as the manufacturers were willing to present for publication, together with the price of the paint submitted, at present market conditions.

Under this arrangement paint manufacturers have submitted 18 samples of paint for test, together with the necessary funds for preparation of surface and application.

Through the assistance of Mr. George S. Webster, Chief Engineer and Surveyor, Bureau of Surveys, Philadelphia, Pa., Mr. F. H. Cubberley, Assistant Engineer in the Division of Bridges of the above Bureau, has been granted leave of absence so as to serve as Director of Tests in charge of this work.

The space assigned to the Committee by the Pennsylvania Railroad consists of two spans entirely over water, from the fifth pier north of the draw to the Perryville end of the bridge. These spans consist of nine equal panels about 30 feet long. The space will be divided through the middle of each panel so as to include a vertical member and half the tie rods for each paint.

The building occupied by the contractors during construction of the bridge will be used for the storage of samples, preparation and painting of panels, weighing of paint applied to the bridge, etc.

The service panels will be attached to the I beams on the south side of the bridge on panels where its respective paint has been applied.

The Director of Tests will be assisted by one of the painters of the Pennsylvania Railroad shops at Wilmington, Del., and a painter who has been trained by Mr. G. W. Thompson, of the National Lead Company, in the very important work of painting panels at a fixed spreading rate.

The Director of Tests will be governed by the following general instructions:

INSTRUCTIONS FOR THE DIRECTOR OF TESTS.

In connection with tests of protective coatings on Pennsylvania Railroad Bridge at Havre de Grace, Md., as issued by authority of Committee E of the American Society for Testing Materials.

The Director of Tests shall have full supervision and charge of the paints submitted for tests and of the work and conditions of application unless otherwise specified by individual manufacturers.

He shall receive all paint submitted for test and shall retain the

same in his possession until issued for work. On the container of each lot of paint he shall paint in indelible black letters the number assigned to the manufacturer of said paint by the Committee as determined by lot. Paints submitted by other manufacturers subsequent to this date shall receive consecutive numbers in order of receipt.

After attaching to the packages the identifying numbers the Director of Tests shall, with red paint, entirely obliterate from the packages the names of the manufacturers and all other identifying marks, excepting the designating numbers as aforesaid.

To each individual paint shall be assigned a single complete panel or member of the bridge, which panel shall be numbered corresponding to the numbers of the packages of paint to be applied. The paint used on each panel shall be that corresponding in number to the number of the panel.

The Director shall make a report of the condition of the unopened packages and of the contents of each package when opened, retaining full details of marks, etc., on the packages before these are obliterated. After obliteration of the marks each paint shall be known only by the number.

Before the beginning of work on any section of the bridge, the Director shall see that the surface has been properly prepared in accordance with the instructions of the Committee as detailed in its circular letter of January 31st, which shall also govern him in other details in any case where specific instructions are not herein given.

The Director is provided with a wet and dry bulb thermometer and with a standard thermometer, and it shall be his duty to make three daily observations with each, one at the time of beginning work, the second at noon and the third at the time of ending work for the day; and in connection with the number of each paint being applied during that day, the temperature and humidity at these three periods of the day shall be recorded, it being understood that no paint used in this test shall be applied on any day when the humidity exceeds about 80 per cent. The Director is also expected to make general notes regarding the state of the weather at the time of application of each individual paint.

Paint for use shall be issued by the Director by number, and the quantity issued shall be recorded in each instance, and the remainder left after the completion of the work shall also be weighed so as to give definite information as to the spreading rate of each individual paint.

Where specific instructions as to the mode of application or other details shall have been furnished by the manufacturer, the Director shall see that such instructions are followed explicitly by the workmen. In case no such instructions have been furnished by the manufacturer, the Director shall have general supervisional work in accordance with the provisions of the Committee's circular letter of January 31 before referred to, which shall govern him in all respects.

In the course of application of each individual sample the Director

shall obtain from the workmen general information as to the working qualities of the paint, as well as such other particulars as may suggest themselves to him as useful. In each instance he shall also note particularly the rate of drying and the physical appearance of each coat.

In regard to the number of coatings to be applied in each instance the Director shall follow the markings on the separate packages of paint, and he shall record in connection with each the weight of paint required for each coat applied. In case no instructions have been given by the the manufacturer as to the time to be allowed between coats, the instructions of the Committee as detailed in its circular letter of January 31 shall rule: that is, five days minimum between coats. No thinning or other additions to any paint shall be allowed by the Director unless the manufacturer of any paint shall have otherwise directed, when the manufacturer's directions shall be carefully observed.

The Director shall make daily reports to the Chairman of the Committee according to instructions to be provided by said Chairman.

The painting of the check panels provided for by the Committee shall be under the general supervision of Mr. Ekey, but the Director shall make careful note of all details in regard thereto in connection with his notes on the general work.

The salary of the Director of Tests shall be at the rate of $150.00 per month; his actual traveling expenses in connection with the work to be paid by the Committee, who shall also pay for necessary labor in connection with the Director's work on the tests.

The Committee will see that the above conditions are strictly observed, and assure the paint manufacturers that the paints will be properly applied to clean surfaces.

The actual painting of the bridge is being done by the firm of J. W. Webber and Sons of Philadelphia, the contractor employed by the Pennsylvania Railroad. Mr. Webber appreciates the conditions of the test and assures the Committee of his hearty support and cooperation in maintaining the above conditions.

In presenting this report to the Society it is realized that there will be more or less criticism both now and as the test proceeds and as results are obtained, but it will be appreciated that this report is the result of long, consciencious, and laborious work on the part of the Committee. The interests and conditions entering into the problem of protecting iron and steel are as different as the pigments used in the paints.

All of these conditions have been harmonized as far as possible, variables eliminated to the utmost, all questions of bias, prejudice, or interest controlled, so that the Committee expects to place in

the hands of the Society valuable data on the protection afforded by paint when applied to bridge steel in this general latitude.

A comparison of the paint films on the service panels and on the full sized structure should determine the value of perfectly cleaned surfaces painted under the most favorable conditions with known amounts of paint.

This report can only be considered a report of progress, the results are to be obtained as they develop and are determined on inspection by the Committee.

It is hoped, however, that this test is only the beginning. Other tests should follow on different types of structures, arranged on fundamentally different lines of attack to eliminate even more completely some elements of uncertainty.

The Chairman of the Sub-Committee on the Preparation of Iron and Steel Surfaces for Painting recently addressed a circular letter of inquiry to a number of firms and individuals prominently interested in the subject which, together with the replies thereto, appears as an appendix to this report.

Respectfully submitted on behalf of the Committee,

S. S. VOORHEES,
Chairman.

JOSEPH F. WALKER,
Secretary.

APPENDIX.

The chairman of the sub-committee of Committee E on the Preparation of Iron and Steel Surfaces for Painting addressed the following letter of inquiry to a number of users and manufacturers of preservative coatings:

DEAR SIR:—

I herewith enclose a reprint from the Proceedings of the "American Society for Testing Materials" on the "Preparation of Steel Surfaces for Preservative Coatings"*.

The general practice of the assemblers does not admit of very careful cleaning of steel surfaces before painting, and as a rule, is not urgently insisted upon by the engineers in charge. It is a known fact that mill scale contains a large percentage of Oxygen and that it induces further corrosion, which necessitates its removal from the surface, as it is destructive to both the steel and the preservative coating.

It appears to me this question should be thoroughly discussed in engineering circles in order to arrive at some definite plan that is both practicable and least expensive, by which the mill scale can be disposed of before painting and then to insist that the plan be carried out.

I ask for your criticism of this article and suggestions as to how to obtain the results desired, as it is my wish to get the opinions on this subject of the leading engineers and architects of the country and of others interested in this class of construction, that I may tabulate them in the form of a report to present at the next annual meeting of the "American Society for Testing Materials."

(Signed) J. W. WHITEHEAD, JR.,
Chairman of Sub-Committee on
Preparation of Iron and Steel Surfaces for Painting.

The following replies to this inquiry, given in alphabetic order of the writers, were received:

From Alfred P. Boller, of Boller and Hodge, Consulting Engineers:

In reply to your inquiry concerning the preparation of iron and steel surfaces for painting, I would say that the importance of the subject cannot be overrated. It has long claimed my thoughts and attention, but I

* Vol. V, p. 95.

have never yet come across a satisfactory workable scheme in these days of "rush tonnage." Sand blasting is out of the question as a commercial method, it being utterly impracticable in general shop practice, except possibly in some special cases, where time and cost are no object. The removal of scale in the shop during fabrication can only be very partially done, as the time element required for its entire loosening cannot be considered in modern shop practice, where any delay in the sequence of operations is impossible.

As scale is admittedly a bad condition over which to paint, and as exposure will shortly loosen it so as to enable its removal by brushing or scraping, and having in view practicable shop conditions, it seems most reasonable to omit all shop painting as proposed by you, and let nature put in its work after erection, until the scale is so loosened up that it can be scraped and brushed off, when a fair surface for receiving a priming coat can be obtained, which priming can be well and properly done, as time is no object at the expense of thoroughness.

I notice in the Proceedings of the American Society for Testing Materials Mr. Shankland not only endorses the views you have advanced, but has put them into practice on important structures with satisfactory results, so far as three years show up.

I am inclined to think with you that the only practicable method of properly priming structural steel is to do it after erection when the mill scale has become loose, instead of at the shop, except for such parts as may be inaccessible in the field.

From F. O. Bunnell, Engineer of Tests, Chicago, Rock Island and Pacific Railway:

Answering your inquiry, relative to method for removing scale from structural material, I would state that my personal experience in dealing with this subject has been quite limited. However, I have always felt that the manufacturers, for some reason or other, were not favorably disposed toward developing a sand-blast system. I believe that with the earnest co-operation with the manufacturers in developing this system, a more favorable showing can be made with the sand-blast system than has been made heretofore.

From F. P. Chessman, National Paint Works:

I beg to quote herewith from my booklet, which covers the subject according to our belief, "As to the best methods of preparing metal surfaces for painting".

We have recently had our attention called to a case where the metal had been prepared by sand-blasting and the surface had been so highly polished and smoothed by the sand-blasting that the paint did not adhere, showing that one can get too much of a good thing in sand-blasting as well as in other matters.

1. Poor surface and improper application.

As before stated more paint is ruined by poor application than in any other way; hence, we class it as the greatest cause for the failure of paint. It has been our experience that not once in twenty times is the surface free from corrosion, mill-scale, grease or dirt when the paint is applied The painter is generally not a skilled mechanic, and the paint is put on under all kinds of temperature and degrees of moisture, often rained, frosted or snowed on before dry; also frequently thinned with cheap worthless oils and japans, and the greatest wonder is that, under these conditions, it stands as well as it does.

It makes a vast difference in the durability of the paint as to the character of the surface to which it is to be applied. If the steel is rolled cold or nearly cold the scale will come off much quicker and easier than if it is rolled hot; when rolled hot the scale is pressed in and takes many months frequently before working free, then it carries the paint with it.

Pickling the metal at the mill is the best method for removing mill scale. The next best operation is the sand-blast at the mill. It costs from 75 cents to $2.00 per ton for pickling, and from 60 cents to $1.75 per ton for sand-blasting. When the metal is not cleaned at the mill to obtain the greatest durability on work that can be reached to be cleaned off, it would be best to apply only a shop coat of our No. 51, then after this is allowed to stand from six months to a year, depending upon whether the steel was hot or cold rolled, this first coating should be completely removed by burning off with the painter's torch, first giving the metal a coat of benzine. This is our first choice, as it removes the moisture as well as the scale, or by sand-blasting as a second choice, or with wire brushes, which, however, do not do the work as well as it should be done. Then two, or better still three, coats of paint applied, the kind of paint depending on location and condition of exposure.

We regret to say, however, that we do not believe that this ideal method of properly preparing the surface will be followed by many, as they will think it rather expensive, and yet it would prove itself the cheapest in the long run.

From Edward K. Coe, Assistant City Engineer, Duluth, Minn.:

My experience in preparing steel for painting is not extensive, but your discussion came at the right time to give me valued support, when I was receiving much adverse criticism for having 125 tons of steel erected without a shop coat of paint, as an experiment. The steel was exposed to two months of rainy weather and accumulated a coat of red rust. This was removed with hammer and wire brushes, leaving a bright surface on which to paint. Thus far the results seem better than those usually had. I offer this merely as a straw in corroboration of your evidence and that of Mr. Shankland. I may add that I was moved to the experiment by having seen, in 1904, a 2½-inch anchor bolt, 9 feet long, which had been

bedded two years in concrete, break at the bottom nut and pull out. It had doubtless been placed when too new.

From J. B. French, Bridge Engineer, the Long Island Railroad Company:

I have read your discussion with much interest and though we have not yet gone as far as to specify that steel work shall not be painted in the shop, except where inaccessible after erection, I am fast coming to the conclusion that that course is best calculated to meet the existing conditions.

Shop painting as now done in most shops frequently does more harm than good, and as long as present conditions continue, it seems impossible to improve the practice. The difficulty is almost entirely a matter of workmanship including both the preparation of the surfaces and the application of the paint, and is largely due to lack of room in the shops and shipping yards and to the cheap labor employed. Our experience is that more harm is done by putting on too much paint rather than too little, providing the surfaces are covered at all.

We have recently been getting a large amount of steel work for construction in which, after erection, it will be either partially or entirely covered with Portland cement concrete, or mortar, and to cover this class of construction our specification reads—"that surfaces which the construction plans show are to be in contact with concrete or Portland cement mortar, shall not be painted." For various causes much of this steel work has been exposed to the weather for six to eight months before the concrete has been placed to cover it, and while it has become largely covered with red rust, it has cost very little to do the necessary cleaning to allow the concrete to be deposited. No attempt is being made, however, to take off more than the rough flakes and scale, the thin red film being considered as doing no harm where it is to be covered by concrete.

The only objection to having the shop coat omitted from surfaces which are accessible after erection, arises from the uncertainty in regard to the time which will elapse after the delivery of the material and before it can be erected. It would seem desirable, therefore, if this interval is likely to be longer than two or three months, that a coat of thin paint should be applied when the material is unloaded for storage, and in the case of railroad companies this should be done by their own forces. It is the present practice of this Company to purchase the paint and to do all the painting which is to be done after the material is delivered, and where the purchaser has sufficient work to maintain such an organization that is undoubtedly the wise course to pursue.

Under present conditions, therefore, the writer considers that it is useless to agitate a modification of the specified requirements for shop painting other than to cut out the shop coats, except for assembling and for the surfaces inaccessible after erection, altogether, and to have all further painting done by the purchaser after the material is delivered.

From Phelps Johnson, Engineer, Dominion Bridge Company, Limited:

I have had no practical experience whatever with sand-blasting or other special methods of preparing steel and iron for painting. In my experience I have found that an exposure to the weather for three or four months will ordinarily loosen nearly all the mill scale adhering to rolled material, and have considered that the subsequent removal by steel brushes of the slight coating of rust powder that is formed leaves the material in the best practicable shape for receiving the paint. I am of the opinion that the exposure to the weather may be prolonged to say twenty-four months without appreciable waste of metal or injurious pitting or roughening of the surfaces, and that there is but a slight increase in the labor necessary to brush the surface clean for painting. The presence of mill scale on the material when painting may be objectionable, but when it is considered that probably 95 per cent. of all bridge material is worked up, painted and put out from the shops without more than a few days, or at most a few weeks, exposure to the weather, the injurious effect of the mill scale is not in practice very apparent.

From Gustav Lindenhal, Consulting Engineer:

It is true that mill scale contains a large percentage of Oxygen, but it is not true that it induces further corrosion, which necessitates its removal from the surface.

Mill scale is simply the magnetic iron oxide, which is insoluble in most acids, and an excellent preservative of the metal underneath, always provided that it tightly adheres to the surface of the metal. Years ago processes were used to produce artificially, with the aid of superheated steam, on the steel heated to redness, a coat of magnetic oxide of iron, the chemical composition of which is the same as that of the ordinary scale. A scale tightly adhering to the surface is a preservative against oxidation, by reason of holding water by capillary action, which, coming in contact with the metal surface under the loose scale, corrodes the same, and thereafter corrosion progresses as usual at a geometrical ratio, scale or no scale.

I consider the use of sand-blast for the cleaning of metal surfaces not only useless, but detrimental.

A process of cleaning which will leave tightly adhering scale on the metal and remove the loose scale is to be commended. Paint in its multifarious forms depends upon linseed oil forming a protective skin. The mixture of powdered solid bodies for thickening the paint must not mislead us into the belief that these admixtures afford greater protection than does the linseed oil.

The problem of painting iron and steel is not yet solved, in spite of the volumes of papers, discussions and reports on investigations which encumber the bookshelves.

From A. H. Sabin, Chemist:

My opinions you know pretty well; they have not changed. You will find them in my book, "Technology of Paint and Varnish." Also in a pamphlet on "Theory and Practice of Painting on Metal," from which I quote as follows:

SPECIFICATIONS FOR BEST WORK.

All iron and steel, after being shaped, punched, bored and otherwise made ready for assembling, must be cleaned by the sand-blast or other equally efficient means, so as to show, in all parts, the grayish-white color of the metal.

The cleaning of structural steel work by the use of the sand-blast is probably the simplest and most satisfactory way to have it done. The great objection to this, as to all such work, is the cost. Since there are practically no plants for doing such work in bridge shops—in fact there are no plants for cleaning steel by any process—any engineer who decides to call for thorough cleaning must expect to pay an additional sum for such work, which, if the work be of small extent, will be disproportionately great in comparison with the work actually done; but if the work be of great extent the incidental cost of the plant will make but a small item in the total cost. Plants have been installed since the publication of the first edition of these specifications by several of the railroad companies for cleaning bridges in place, by some municipal engineers and by some manufacturing works where structural steel is treated. It has been objected that this is a patented process; it is therefore in order to observe that the original patent, under which work of great extent was carried on most successfully for fifteen years, was issued to General Benjamin G. Tilghman, of Philadelphia, on October 18, 1870. being No. 103,408, and has therefore expired long ago.

SPECIFICATIONS FOR ORDINARY WORK.

Shortly before riveting, all such parts of surfaces as are to be brought permanently into contact, shall be thoroughly cleaned from dirt and rust, and from all scale which does not perfectly adhere to the metal, by the use of scrapers, chisels, and wire brushes; the latter alone shall not be considered sufficient.

The wire brush is an efficient means of getting rid of loose scale and dirt; but it is practically worthless for removing thick rust or anything which adheres closely. Much of such material may be removed by steel scrapers, but deeply corroded spots should be thoroughly cleaned out with a chisel, and then well brushed. These crevices are hereinafter to be inaccessible; and they are subject to the most dangerous corrosion, because rusting at such places impairs not only the strength, but also the stiffness of the structure—a matter of much importance. These joints therefore deserve more care than any other part.

From George E. Thackray, Structural Engineer, Cambria Steel Company:

I believe that you are mistaken in stating and believing that mill scale contains material which induces further corrosion, as it is quite a stable compound, and on steel which is finished at a medium temperature, leaving the scale well rolled in and adhering to the metal, this alone will protect the surface for a long time. Of course some steels contain loose or blistery scales which, for mechanical reasons, should be removed before painting, as otherwise they would fall off and carry the paint with them.

In this connection I quote below from a paper on the Methods of Testing the Protective Power of Paints Used on Metallic Structures, presented by Mr. E. Ebert to the International Association for Testing Materials, with which our Society is affiliated.

"The view previously entertained by many manufacturers that the formation of rust tended to promote further oxidation by chemical means and that therefore preparations of oxide of iron exercised a prejudicial effect, has as the result of extended experiment, been fully and completely disproved."

"Though the importance of cleaning has been pointed out it does not, however, follow that the iron surfaces must be absolutely bright. Experiments which were carried out in the years from 1892 to 1896, in order to ascertain what was the effect of cleaning, have proved that it is fully sufficient, in order to free the iron from all impurities, to go over it with a wire brush or scraper, or if need be to employ a hammer to knock off any adhering scale. The layer of oxide or rust which remains after this treatment does no harm and it is in fact serviceable, as the preparation adheres better to it than it would to a bright and polished iron surface."

As to sand-blasting, I agree with you that this is almost useless and impracticable, as I have seen sand-blasting done, exposing the metal surface, which was soon covered with a thick coat of rust before the painters could reach it, although both the sand-blasters and painters were working with expedition.

DISCUSSION.

THE CHAIRMAN (MR. G. B. HECKEL).—I think that the report shows some of the troubles that the Committee has had. It is a very broad subject, about which very little is known, and about which very much knowledge is desirable. I do not think the Committee expects to settle all the problems confronting manufacturers or consumers; but it does expect to obtain from these tests some very valuable information; and as far as possible the Committee is equalizing conditions and guarding results. As the report says, there will undoubtedly be criticism. The Committee may make mistakes; but as far as it is possible I feel sure it is going to avoid them. **The Chairman.**

MR. H. H. QUIMBY.—Has the Committee considered the possibility that some manufacturers may submit for test a very different quality of paint than that generally furnished by them to the public, and the consequent lack of value of the test, were manufacturers unwilling to have the Committee use samples obtained in the open market? I should like to ask, also, whether different kinds of oils are represented in the paints submitted for test; whether there are paints made with other oils than linseed? **Mr. Quimby.**

MR. S. S. VOORHEES.—In reply to the first question, in these tests it was impossible to get any paints except those submitted by the manufacturers themselves. We have attempted to govern the quality of their paint by the price at the present market condition. **Mr. Voorhees.**

In regard to the second question, the analysis will show what oil and what pigments were used in these paints. It is stated in the report that the analysis will be included in this work.

MR. QUIMBY.—I do not see how the question of price will determine the fact that the paints submitted for test are the paints that are sold to the public; in other words, whether the manufacturers will submit a special paint, different from what they ordinarily manufacture and what the public gets when it buys it. **Mr. Quimby.**

THE CHAIRMAN.—I think that this special work is intended to be but the beginning of a series of similar tests made by this **The Chairman.**

The Chairman. Committee; and in the present case, as I understand it, the Committee, in order to make a start, opened this test to the manufacturers and allowed them to furnish paints. In connection with these paints, I believe, the makers give the prices at which they are willing to supply duplicate paints under present market conditions. As I understand it, the Committee intends to carry this further and to do independent work along this same line with paints bought in the open market. It is the general understanding, I believe, that the work of the Committee is by no means completed with this test.

Mr. Thompson. MR. G. W. THOMPSON.—Without speaking for the Committee, of course, I would mention that some of these points have been discussed at various meetings of the Committee; and while it was exceedingly desirable that information should be given on a purely scientific basis, the Society had no funds at its disposal to conduct such a purely scientific examination of paints. The best they could do was to get the manufacturers to supply the paints and supply the money to put them on; and they hoped that by the classification of the paints they could report the results independent of the manufacturers. In other words, the purpose is not to give any manufacturer any commercial preeminence, as I understand it. It may result, on inspection, in the discovery that certain paints have stood well in their respective treatment; and we want all the information that can be gotten in regard to those paints and in regard to the paints that stand well; and yet the manufacturer himself must be separated, to a certain extent, from the paint. We do not know of any other way in which the manufacturer can be protected, and yet, at the same time, a definite amount of benefit given him. If a certain paint happens to turn out well, it does not seem altogether right (even though the manufacturer has supplied the paint and money) that this should be used for advertising the product of that particular manufacturer; and, as I understand it, the Committee—the Special Committee that Mr. Voorhees has referred to—is to take up, and the whole Committee is to take up, the question as to the extent to which the results of these tests will be made public.

If we find that certain carbon paints give certain results, certain oxide paints give certain results and certain lead paints give certain results, we can tabulate the results in connection with

the classification of the paints. Whether much more than that can be done is a question the Committee will have to work out. We have made a start by getting these paints applied under favorable conditions; afterwards we shall have to study means of making the report. We have undertaken a pretty big proposition; and the thing that we must congratulate ourselves upon is that so many manufacturers have been willing to supply the materials. Mr. Thompson.

MR. VOORHEES.—I am very glad, indeed, that a paint manufacturer should speak from his standpoint. It is not the intention of this Committee to recommend any specific brand of paint. Whether the material offered is a standard paint or a special paint made for us, is a question which has received our consideration; and we appreciate that our tests may not be as perfect as they might be on that account; but in this present instance there was no way to avoid it; and, as stated in the report, it is hoped that this will prove a starting point for other series of tests on other types of structure along different lines of attack. Mr. Voorhees.

MR. A. B. HARRISON.—I should like to ask whether the results obtained on time tests on this bridge at Havre de Grace are to be published by this Society. Personally, as one of the contestants, I should like the results of this very interesting test published in full, giving the scientific world at large the benefit of the information obtained as to the efficiency of the various paints and coatings. Mr. Harrison.

MR. VOORHEES.—The intention of the Committee is to report on classes of paint. That was our idea in the rather searching questions regarding composition. We were in hopes that we would get data from the manufacturers, enabling us to classify the paints and put them where they belong. Now we will have to depend on our analysis. In most cases we will be able to classify them exactly; in some instances the analysis may not give us full information. Mr. Voorhees.

MR. KNOWLES.—I should like to ask, if the method of cleaning by sand-blast is considered a failure; whether it is thought too expensive or too unwieldy? Mr. Knowles

MR. VOORHEES.—It was the original intention that half of some of the panels should be thoroughly cleaned to clean bright metal by the sand-blast, and the other half cleaned in the ordinary manner with chisel and wire brush. Mr. Voorhees.

Mr. Voorhees. The same paint was to be applied to each half. From the result of these tests it was hoped that data could be obtained relative to the economic value of the two types of cleaning, but unfortunately sand-blasting was not practicable in this test and it was dropped.

We have the comparison, however, between the panels painted on perfectly clean surfaces, the paint applied under most perfect conditions by skilled painters, and the bridge. The painting of these panels themselves is a work which requires a great deal of thought and expense as it requires a weighed amount of paint applied to a fixed surface. We shall have, from these panels, the effect of three known amounts of paint on a given surface. The oil paints will be spread at the rate of 600, 900 and 1,200 sq. ft. per gallon on perfectly clean surfaces. These will be exposed alongside of the bridge panels which have been prepared as stated.

Mr. Knowles. MR. KNOWLES.—How are the auxiliary plates which are to be perfectly clean prepared?

Mr. Voorhees. MR. VOORHEES.—They are pickled in 10 per cent. sulphuric acid, neutralized in carbonate of soda, washed in running water, packed in lime until ready to be painted, the excess of lime washed off, dried at a temperature of about 212° Fahr. or higher just before the paint is applied.

Mr. de Wyrall. MR. CYRIL DE WYRALL.—I am glad to see the Committee has done away with the expense of sand-blasting. In my experience in sand-blasting along the line of the subway in New York, we went to the expense of thousands of dollars to sand-blast columns. We placed them side by side with others that were cleaned in the least expensive way, by hammers, scrapers and wire brushes, and on exposure from one to four or five years, we find not the slightest difference in effect as between sand-blasting and the cleaning by hammers and chisels. There is just as much corrosion in the one case as in the other.

Mr. Voorhees. MR. VOORHEES.—Do I understand the paint was applied immediately after sand-blasting? I should say, in that connection, that a perfectly clean surface is very susceptible to corrosion. The corrosion begins immediately, as we find, in our panels. These panels are pickled and neutralized in soda and kept in lime until the paint is to be applied, and the same thing is true of a surface

which has been sand-blasted: the clean metal is very rapidly corroded. **Mr. Voorhees.**

MR. DE WYRALL.—We sand-blasted some, under the best conditions, that is under a shed; but even then we found that from the time that the man could get his brush in the pot and put the paint on, hygroscopic moisture had formed in sufficient quantity to start corrosion, which continued to form under the paint composed of red lead and linseed oil. Then we had a sand-blast at work in the subway and had the painters follow right up as quickly as they could; but the result was the same. In fact, I believe, some of the columns that were sand-blasted corroded sooner and more rapidly, and continued to do so from the time they were put in until we cleaned them off. **Mr. de Wyrall.**

MR. VOORHEES.—This is a very important matter, and we need more information on this question of sand-blasting. The paint manufacturer claims that the failure of the paint is due in many cases to imperfectly cleaned surfaces. The engineer desires to know how much money he is warranted in spending on cleaning the surface. Any information on this point is of great value. Undoubtedly, a properly cleaned surface will give better protection from paint applied. But is the cost warranted? That is the point. **Mr. Voorhees.**

MR. HARRISON.—As a paint manufacturer, I have given up all hope of having surfaces properly prepared and painted. Let us do the best we can under the conditions as they prevail, and not as we should like to have them or as they ought to be. Put the paint on in the way it is usually done, not in the way in which it can be done or in the way we want the painters to do it. It seems to me that the efficiency of a coating can be determined very much more accurately in such a test than when the surface is especially prepared under especially favorable conditions. For instance, coat a surface that has not been properly cleaned and which is rusty, then let the paint stand or fall by competitive results as to efficiency. Also, coat the surface of iron when there is humidity and dampness, even wet iron, and note comparative results with different coatings. It seems to me that information secured by this Society under such conditions, which we all know are prevalent, would be of especial interest. **Mr. Harrison.**

MR. DE WYRALL.—I am sure, from observation I have made **Mr. de Wyrall.**

Mr. de Wyrall. in the last sixteen years, that if we could get a coating or a pigment that would form a perfect vacuum it would not be necessary to clean the steel at all. On our 177th Street Station the steel contractor, the Assistant Engineer for the Rapid Transit Commission, and myself made certain observations and diagrams of parts of the structure that had not been cleaned in any way. We cleaned the balance as well as we could under existing conditions. That was about eighteen months ago, and the work was done in the dead of winter when it was too cold to do almost any kind of work. On examining the places where the rust had started before painting, we found on scraping off the coating that the pigments that we used had formed such a perfect vacuum that the corrosion had not spread. I also tried this in the subway three and a half years ago with the same result; but of course there must be a vacuum: corrosion cannot take place in a vacuum. The real problem is to make the paint suit the conditions, not in making the conditions suit the paint; which cannot be done.

REPORT OF COMMITTEE F ON THE HEAT TREATMENT OF IRON AND STEEL.

Soon after this Committee was appointed in 1902, its Chairman prepared a scheme for investigating systematically the heat treatment of steel and from that time until now this scheme has been carried out in the metallurgical laboratories of the School of Mines of Columbia University, in part by the officers and in part by the advanced students in Metallurgy there. Much work has been done in the metallurgical laboratory of Harvard University also, under the direction of your Secretary. We hope that the result thus reached will permit us to formulate with some precision the laws governing this subject; but we prefer to hold back the publication of the greater part of our results until they shall have been well confirmed.

We now submit three papers, which set forth in detail part of the work which has been done. These are:

An Experimental Double-Muffle Gas Heating Furnace for Studying the Laws of Heat Treatment of Steel. By Henry M. Howe.*

The Effect of Heat Treatment on High Carbon Steels. By William Campbell.†

The Burning, Overheating and Restoring of Nickel Steel. By George B. Waterhouse.‡

Respectfully submitted on behalf of the Committee:

HENRY M. HOWE,
Chairman.

ALBERT SAUVEUR,
Secretary.

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* See p. 202.
† See p. 211.
‡ See p. 247.

REPORT OF COMMITTEE G ON THE MAGNETIC PROPERTIES OF IRON AND STEEL.

The Committee held a meeting at Pittsburg, Pa., November 26, 1905 to discuss its work for the coming year. In view of the fact that there is not a general knowledge of the fundamental principles of electricity and magnetism, it was the opinion of the Committee that they could best devote their attention this year to the preparation of a report which would set forth in clear, concise form, free from technical terms, some general information with regard to magnetism and magnetic materials.

The Committee has been in correspondence with nearly all of the makers of iron and steel for electrical purposes in this country, and with the majority of the manufacturers of electrical machinery as well.

The discussion at the meeting and the subsequent correspondence with steel manufacturers and electrical companies, indicates that the present status of the subject is about as follows:

1. There are in use in this country two systems of magnetic units: the so-called C. G. S. or Centimeter-Gram-Second and the English systems. These two systems will be explained later in the report.

2. There is need for a means of rapid transformation from one system of units to the other, such as tables setting forth the relative values of the units in the two systems, and the constants required for converting one system to the other.

3. The scientific terms in which the magnetic units and magnectic properties are commonly expressed are not generally well understood.

4. Almost all of the methods of making magnetic tests now used give results of relative accuracy only, so that great difficulty is experienced in the comparison of results when different methods of testing and different systems of units are employed.

5. Tests which are at present made by electrical manufacturing companies, range from tests of only the finished machines on the part of a great number of the smaller manufacturers, to the most careful and exhaustive laboratory tests by other manufacturers, especially those using a large amount of material.

6. On the part of the manufacturers of steel, the Committee finds that some of the manufacturers have well equipped laboratories, and make regular tests of their product. Others regularly or occasionally submit samples of their product to experts who make the tests. A number of steel manufacturers do no magnetic testing whatever, but rely entirely upon the chemical analyses of the material.

7. The Committee does not consider it advisable to recommend standards for magnetic materials at this time, nor to suggest the adoption of standard methods of making magnetic determinations.

8. The Committee submits the following paragraphs with regard to magnetic materials in the hope that they will assist those who have to do with the preparation and consumption of iron and steel for magnetic purposes to more readily understand magnetic phenomena and the requirements of magnetic materials. No apology is made for the non-technical character of the report, in fact the Committee has endeavored to depart as far as possible from the use of scientific terms.

Some of the parts of practically all electrical apparatus consist of iron which is in a magnetized state. These magnets are of one of two kinds, "electro-magnets" or "permanent" magnets. An electro-magnet is one in which the magnetism is temporary; it is not permanently retained by the iron, but is produced in it by passing currents of electricity through turns of insulated wire which surround the iron; the magnetism almost wholly disappears as soon as the current ceases to flow. In the sense that currents of electricity have a direction of flow, magnetism is also considered as having a direction, and if the direction of the current producing the magnetism is changed, the magnetism will change also. Permanent magnets are those which, when once magnetized, retain a considerable portion of the magnetism and do not require the action of currents of electricity to maintain their magnetic state.

Iron is used in making electro-magnets because it is the best conductor of magnetism known and is by far the cheapest of all the magnetic materials. There is no substance known through which magnetism can not be caused to pass, but iron has the peculiar property of being an especially good conductor of magnetism.

There are two systems of magnetic units commonly used

in this country, namely the Centimeter-Gram-Second system, and the so-called English system. There are two magnetic properties of iron which it is important to know; the permeability and hysteresis.

When a piece of iron is magnetized by the action of an electric current flowing in a coil, the magnetic intensity produced varies with the strength of the magnetizing force per unit of length of the circuit. The total magnetizing force is represented by the product of the number of turns and the current which is flowing in them. In the English system, the magnetizing force is measured in ampere turns per inch of length, which is the product of the number of turns and the current divided by the length of the circuit in inches. In the C. G. S. system the unit of magnetizing force is the gilbert, which is the magnetizing force which would be required to produce unit magnetic intensity in a circuit composed of air one centimeter in cross section and one centimeter in length. Thus we have the two units of magnetizing force, the ampere turn per inch and the gilbert per centimeter. The relative values of these units will be found in the tables elsewhere in this report.

If a piece of iron be subjected to a constantly increasing magnetizing force, the intensity of magnetism produced will also be increased, but not in direct proportion to the increase of magnetizing force, or, in other words, with increasing intensities the ratio of the intensity to the magnetizing force decreases. This ratio of magnetic intensity to the magnetizing force producing it, is called the "permeability." It will be seen that this property is not a constant for a given piece of material, but varies with the magnetic density. In general terms, it may be said that the permeability of iron is a measure of the ease with which it may be magnetized.

At low intensities, the magnetism increases rapidly as the magnetizing force is increased, and when the density reaches the point where the permeability becomes low the increase in magnetism is less rapid and the iron is said to be saturated.

It is also a fact that different kinds of iron and steel have different permeabilities even when magnetized to the same density. As a rule, iron which is nearly pure, free from large percentages of combined carbon or other impurities, like sulphur and manganese, has high permeability. Iron which is hard or which is very impure,

usually has rather low permeability. The magnetic quality of a sample of iron is affected by the chemical content, and the physical treatment to which the iron is subjected. The effect of the presence of any impurity is determined largely by the percentage of other impurities present, so it is practically impossible to establish any exact relation between percentages of different impurities and the magnetic quality. Again, the effect of physical treatment, such as annealing, cooling, etc., is dependent to a great degree upon the chemical composition. The quality of an iron, so far as its permeability is concerned, is usually expressed in the form of a curve, with magnetic densities as ordinates and the corresponding magnetizing forces as abcissas.

The unit of magnetic intensity in the C. G. S. system is the gauss, which is one magnetic line of force per square centimeter. In the English system, the unit is sometimes expressed as kapp lines, but more often as a maxwell per square inch. In the C. G. S. system of units, a maxwell means one magnetic line of force without any reference to the area or the intensity, and the total number of maxwells in a magnetic circuit simply expresses the total number of magnetic lines in the circuit, or the magnetic flux, as it is termed. It is very common to find magnetic densities expressed as so many gausses or as so many maxwells per square inch. The relation between these two units will be found in the accompanying tables.

The unit of magnetic resistance, or reluctance, as it is termed, is the oersted, which is the reluctance of a path composed of air one centimeter in length and one square centimeter in cross-section. The permeability of air and almost all materials is unity; that is, the intensity of magnetism produced is equal to the magnetizing force per centimeter of length of the circuit.

Conventional forms for expressing intensity, magnetizing force and permeability are largely used. The capital "B" stands for intensity in the C. G. S. system, and capital "H" for the magnetizing force in gilberts per centimeter, so that curves representing the relation between intensity and magnetizing force are frequently styled "B and H curves." They are often incorrectly called permeability curves.

Manufacturers of electrical machinery desire to obtain iron of high permeability in order to make the magnetic circuit as small

as possible, thereby reducing the weight of iron, and also the amount of copper and current necessary to produce the magnetism. It is desirable also that the magnetic quality be quite uniform, in order that the operation of the electrical machines may be closely predetermined, and so that a large number of machines when made at the same or at different times, will test out alike. Uniform magnetic quality makes possible the use of standard dimensions and windings for standard machines.

Testing iron for its permeability consists in determining the intensity produced in the iron by magnetizing forces of different magnitude. The problem then resolves itself into the preparation of the sample in such a form that it can be magnetized; a means of producing the magnetism in it, and a method of accurately determining the magnetism produced and the magnetizing forces producing it. The determination of the magnetizing forces in any method of testing is usually a very simple matter, since it can be calculated from the number of turns of wire and the currents used. The determination of the intensity produced by the different magnetizing forces is not so simple, but many methods have been devised for measuring it.

Some of the more important requirements of the method of making this test of iron are: First, the specimen should be of simple form, so that it can be easily obtained and be cheaply prepared; Second, since any method of determining the amount of magnetism produced in the specimen will indicate the total magnetic flux, the area of cross-section of the specimen must be known, and should be uniform in order to obtain the intensity; Third, if possible, the shape of the specimen and the method of testing should be such that it will not be necessary to wind a special coil for each sample tested, but rather to use a specimen which can be inserted in a coil made for this purpose.

One of the simplest forms of specimens is an annular ring without any joints, turned to a uniform cross-section. This has the advantage that the cross-section is uniform and is composed throughout of the same material without any joints or air gaps. It has the disadvantage that the winding must be placed on each specimen. It is also rather difficult to test. (See Proceedings, Vol. IV., 1904, p. 180.) Where the sample to be tested is in the form of a bar or any shape where the magnetic circuit is not complete, it is

necessary to complete the magnetic circuit by a circuit of either known or negligible magnetic resistance, so that a correction can be made for this part of the circuit.

In obtaining samples of iron to test, care should be exercised to make certain that the specimen is representative of the material regularly produced. For example, if a test of cast iron is to be made, a very light casting made in a separate mold will usually be subjected to greater chilling than a larger casting, and as a sample for making a test, would not be representative of the quality of the material which would be obtained in larger castings. Again, unless sufficient material is allowed for turning off, the exterior of the casting would have some effect upon the result. In making tests of material which has been subjected to a heat treatment, precautions must be observed, and if possible, it is always advisable to take a sample from a specimen large enough to insure that its quality will represent faithfully the quality of the material. In cutting strips from rolled metal, it should be borne in mind that the direction of the grain and the portion of the sheet from which the sample is cut will have some effect. It is therefore advisable to select samples which will represent an average, both as regards the portion of the sheet from which it is cut and the direction of the grain. A favorite method of obtaining samples of castings is by means of a hollow drill, which when drilling holes, cuts out a round bar which can be subsequently turned up true and tested.

The Committee is now conducting a series of researches upon the relative accuracy of different methods of magnetic testing, and in its next report expects to give the results of these experiments, with discussion of the different methods, and the necessary precautions for obtaining reliable results.

As a means of converting from one system of units to another, the following rules and tables will be of value:

1. Having given a magnetic intensity in gausses, to reduce to maxwells per square inch, multiply by 6.45.

2. To reduce maxwells per square inch to gausses, divide by 6.45.

3. To reduce magnetizing force in gilberts per centimeter to ampere turns per inch, multiply by 2.02.

4. To reduce ampere turns per inch to gilberts per centimeter, divide by 2.02.

5. To find the reluctance of a magnetic circuit of known permeability divide the length of the circuit in centimeters by the product of its cross-sectional area in square centimeters and the permeability.

6. To find the total amount of magnetism which will be produced in a circuit of known reluctance by a given magnetizing force, divide the total magnetizing force in gilberts by the reluctance.

The other important magnetic property of iron is the losses which occur when the iron is subjected to an alternating magnetizing force. The total loss which occurs is made up of two factors,

TABLE I.

MAGNETIC UNITS IN THE C. G. S. AND ENGLISH SYSTEMS.

	NAME OF UNIT.		CONVENTION.		DEFINITION OF UNIT.	
	C. G. S.	English.	C. G. S.	English.	C. G. S.	English.
Density or Intensity.	Gauss.	Maxwell, per sq. in.	B	.....	Line of force per square centimeter.	Line of force per square inch.
Magnetizing Force.	Gilbert.	Ampere Turn.	H	.....	Magnetizing force required to produce unit density.	The magnetizing force of 1 ampere flowing in 1 turn of conductor.
Magnetic Flux.	Maxwell.	Kapp Line.	Φ	.....	A single line of force.	A single line of force.
Permeability.	.....	.....	μ	.....	Ratio of B to H.	.....
Reluctance.	Oersted.	.....	.....	.....	Reluctance of a cubic centimeter of air.	.....

hysteresis and eddy currents. In the cores of transformers and the armature cores of dynamos and motors, the direction and magnitude of the magnetism is at all times rapidly changing. To magnetize a piece of iron is undoubtedly to place it in a certain molecular state, and if the condition of magnetization is constantly changing, the molecular arrangement is changing also. There is a certain magnetic inertia, that is, a tendency to remain magnetized when magnetized and to remain demagnetized when in that state. For example, if we bend a piece of iron, it will have a certain tendency to stay in the position in which it is bent, and before it can be bent in the opposite direction, we must first remove the

Table II.

Relative Values of Gilberts Per Centimeter and Ampere Turns per Inch.

Gilberts per Centimeter.	Ampere Turns per inch.	Ampere Turns per inch.	Gilberts per Centimeter.
1	2.02	1	.49
2	4.04	2	.99
3	6.06	3	1.48
4	8.08	4	1.98
5	10.10	5	2.47
6	12.12	6	2.97
7	14.14	7	3.46
8	16.16	8	3.96
9	18.18	9	4.46
10	20.20	10	4.95
11	22.22	11	5.44
12	24.24	12	5.94
13	26.26	13	6.43
14	28.28	14	6.92
15	30.30	15	7.42
16	32.32	16	7.92
17	34.34	17	8.41
18	36.36	18	8.92
19	38.38	19	9.40
20	40.40	20	9.96
21	42.42	21	10.40
22	44.44	22	10.88
23	46.46	23	11.58
24	48.48	24	11.78
25	50.50	25	12.37
26	52.52	26	12.86
27	54.54	27	13.37
28	56.56	28	13.86
29	58.58	29	14.35
30	60.60	30	14.85
31	62.62	31	15.34
32	64.64	32	15.84
33	66.66	33	16.33
34	68.68	34	16.83
35	70.70	35	17.32
36	72.72	36	17.82
37	74.74	37	18.31
38	76.76	38	18.81
39	78.78	39	19.30
40	80.80	40	19.80
41	82.82	41	20.29
42	84.84	42	20.79
43	86.86	43	21.28
44	88.88	44	21.78
45	90.90	45	22.27
46	92.92	46	22.77
47	94.94	47	23.26
48	96.96	48	23.76
49	98.98	49	24.25
50	101.00	50	24.75

set which has been given in the other direction. This operation requires the expenditure of energy, and if kept up at a rapid rate, will heat the iron. Likewise, to rapidly magnetize and demagnetize

TABLE III.

RELATIVE VALUES OF INTENSITIES IN THE C. G. S. AND ENGLISH SYSTEMS.

Gausses.	Maxwells per square inch.	Maxwells per square inch.	Gausses.
1,000	6,450	5,000	775
2,000	12,900	10,000	1,550
3,000	19,350	15,000	2,325
4,000	25,800	20,000	3,100
5,000	32,250	25,000	3,875
6,000	38,700	30,000	4,650
7,000	45,150	35,000	5,425
8,000	51,600	40,000	6,200
9,000	58,050	45,000	6,975
10,000	64,500	50,000	7,750
11,000	70,950	55,000	8,525
12,000	77,400	60,000	9,300
13,000	83,850	65,000	10,090
14,000	90,300	70,000	10,850
15,000	96,750	75,000	11,625
16,000	103,200	80,000	12,400
17,000	109,650	85,000	13,175
18,000	116,100	90,000	13,950
19,000	122,550	95,000	14,725
20,000	129,000	100,000	15,500
21,000	135,450	105,000	16,275
22,000	141,900	110,000	17,050
23,000	148,350	115,000	17,825
24,000	154,800	120,000	18,600
25,000	161,250	125,000	19,375
26,000	167,700	130,000	20,150
27,000	174,150	135,000	20,925
28,000	180,600	140,000	21,700
29,000	187,050	145,000	22,475
30,000	193,500	150,000	23,250

a piece of iron will result in an expenditure of energy and will produce heat. It is therefore desirable to obtain a steel for transformers and dynamo armatures which will have a minimum loss when magnetized and demagnetized. The loss which occurs due

to hysteresis is approximately directly proportional to the rate at which the magnetism changes, or, as it is commonly stated, the frequency. It also increases approximately proportional to the 1.6 power of the maximum magnetic density which is attained during a cycle. By a cycle is meant a magnetization in one direction beginning at zero, a reduction to zero, then a magnetization in the opposite direction and a reduction to zero. The quality of iron, in so far as this loss is concerned, is usually expressed in watts per pound at a stated frequency or number of cycles per second, at a stated maximum magnetic density.

The other loss which accompanies an alternating magnetizing force is what is termed "eddy currents;" this is simply the currents of electricity which are produced in the iron by the varying magnetic fields, just as the currents are produced in any electrical conductor when placed so as to be traversed by a moving magnetic flux. Inasmuch as these currents are idle and wasteful of energy, the cores of transformers and dynamos are built up of thin sheets, insulated from each other, the sheets being placed so as to break up the paths or circuits of the eddy currents. This greatly reduces the eddy current loss, so that in ordinary apparatus it usually does not exceed more than 25 per cent. of the hysteresis loss.

It is well known that the heat loss in any conductor carrying a current is equal to the product of the resistance of the conductor and the square of the current. Assuming that the resistance of the iron remains constant, the eddy current loss will vary as the square of the eddy currents. The electromotive forces which cause the eddy currents to flow will be directly proportional to the frequency and the magnetic density, therefore, the eddy current losses will vary as the square of the current, and will be directly proportional to the square of the frequency, and the square of the magnetic density. Recent efforts have been made to produce a quality of sheet steel which has a high electrical resistance, together with a low hysteresis, which would tend to reduce the total loss.

Just as a piece of soft iron can be readily bent and straightened with a small expenditure of energy, as compared with a piece of hard iron, so a piece of soft iron can be rapidly magnetized and demagnetized with a small expenditure of energy as compared with harder metal. For this reason, it is desirable to obtain iron which

is nearly pure, and it is almost universally used in an annealed state.

The hysteretic constant is usually defined as the loss in ergs per cubic centimeter per cycle, and depends both upon the chemical composition of the steel and the physical treatment which it receives. The only physical property of the iron which affects the eddy current loss is its electrical resistance. The hysteretic properties of solid metals are of little practical interest, since solid metal is never used where the iron is subjected to an alternating magnetism. There are two ways of producing hysteresis and eddy current losses in iron, both very much alike, and yet somewhat different. One consists in magnetizing the iron by means of a coil of wire in which an alternating current is flowing, as in the case of the core of a transformer. The other consists in rotating the iron in the presence of magnetic fields produced by poles of opposite polarity, as in the case of dynamo or motor.

In testing iron for its losses, it is very difficult to separate with accuracy the hysteretic and eddy current losses, so these are usually measured in combination and termed the "core loss" or "iron loss." A suitable means of determining the losses which occur in a sample of iron must provide a means of producing the alternating magnetism, of determining the frequency, the maximum magnetic density and the loss. The loss is usually stated in watts per pound, the frequency in cycles per second, the maximum magnetization in gausses or maxwells per square inch. If the results of the test are to have a high absolute accuracy, the magnetism in the sample should be fairly uniformly distributed, since the hysteresis losses increase approximately as the 1.6 power, and the eddy current losses as square of the density. That is, if the greater part of the flux be crowded into one portion of the iron, the loss will be greater than if the magnetism be uniformly distributed over the area of the circuit. If it is desired that the results of the tests be applicable to the form in which the iron is to be used, for example, if it is desired to predetermine what the loss in a transformer core would be, then the form of the specimen should bear a fairly close resemblance to the form of the transformer core. The same is true in predetermining the losses in armature cores.

It was discovered some years ago that the continued heating

of iron, due to the losses produced by eddy currents and hysteresis, caused an increase in these losses, which was termed ageing. At that time it was not uncommon to find transformers which, during the first year or two of their operation, showed a very large percentage increase in their iron loss, with the consequent higher temperature rise, and decreased efficiency. By improving the quality of the iron and lowering the initial operating temperature, manufacturers are now able to obtain electrical sheets which show practically no increase in core loss at the standard temperatures of operation, and one of the requirements of iron for use in transformers is that it be non-ageing.

In the manufacture of steel for permanent magnets, high permeability is of no importance, but what is required in this case is that the iron, when once magnetized to a high density, will retain permanently quite a large percentage of the initial flux. Such iron is therefore necessarily very hard, and is always magnetized after having been heated and quenched. Iron of certain chemical compositions and heat treatments will retain a large portion of its magnetism. It is not only necessary, however, that the iron retain a large amount of the initial density, but that it must retain it with a great deal of strength, that is, it must be difficult to demagnetize. In testing iron for permanent magnets, it is usual to determine the maximum density to which it is magnetized, the intensity of magnetism which is retained when the magnetizing force is removed, and the force necessary to remove this magnetism.

The intensity of the permanent magnetism will depend greatly upon the shape of the magnet, that is, the distance between the ends or the poles will affect the flux of the magnet, so that a method of testing a permanent magnet for absolute results, must eliminate the effect of the air gap between the poles. If a bar magnet were tested, and its intensity determined, and then the same magnet bent into the shape of a horseshoe, bringing its poles nearer together, the intensity would be increased, and the real test of the bar itself is obtained only when the reluctance of the circuit between the poles is reduced to zero.

Respectfully submitted on behalf of the Committee:

J. WALTER ESTERLINE, *Chairman.*

REPORT OF COMMITTEE H ON STANDARD TESTS FOR ROAD MATERIALS.

Committee H has made some progress during the past year.

A standard method for the determination of the bitumen in asphalt paving mixtures, refined asphalt and asphalt cement was reported and accepted by the Society at its last meeting.

The details of the method as approved by the Committee will be found below:

THE STANDARD METHOD FOR THE DETERMINATION OF THE BITUMEN IN ASPHALT PAVING MIXTURE, REFINED ASPHALT, AND ASPHALT CEMENT.

The Committee in presenting this method of analysis as a standard, wish it understood that they do not recommend it as the best for general use, as it is longer and in several cases gives no better results than other more expeditious methods, but only as a method to be used as a standard and to be resorted to in cases of dispute.

It was selected after comparing the results obtained by several methods by a number of analysts on five standard samples of various bituminous paving materials sent out by the Committee, because it gave the most uniform results with the various materials and the most concordant results in the hands of inexperienced analysts.

METHOD OF ANALYSIS.

Drying the sample and preparing it for analysis.—It was decided, owing to the great variety of conditions met with in asphalt and like bitumen, that it was impossible to specify any one method of drying that could be at all satisfactorily applied in every case, it is therefore supposed that the material for analysis has been previously dried either in the laboratory or in the process of refining or manufacture and that moisture, if preserved, is only hydroscopic or in such a condition as to be easily removed.

The material to be analyzed, if sufficiently hard and brittle,

is ground and then spread in a thin layer in a suitable dish (iron or nickel will do), and kept at a temperature of 125° C. for one hour. In the case of paving mixture, where it is not desirable to crush the sand grains, a lump may be placed in the drying oven until it is thoroughly heated through when it can be crumbled down into a thin layer with a spatula. From 2 to 12 grams (depending on its richness in bitumen) of the substance after drying is weighed in a large sized test-tube (8 inches long by 1 inch in diameter), the tare of which has been previously ascertained. The tube is then tightly corked with a good sound cork, and shaken vigorously until no asphalt can be seen adhering to the bottom or sides, or if a paving mixture or like material, until the solvent has disintegrated all lumps. Care must be taken that the bottom of the cork should be free from any cracks or holes that might retain insoluble matter from the asphalt, or if not the end of the cork inserted in the tube must be covered with tin foil. Care should also be taken while shaking, to keep one finger on the cork to prevent it being blown out.

The tube should then be put away, still corked loosely, in an upright position and not disturbed for two days, after which the carbon disulphide is decanted off into a second tared tube. As much of the solvent should be poured off as is possible without losing any of the residue. The first tube is again filled with fresh carbon disulphide and shaken as before and put away for two more days. The second tube is also corked and put away in an upright position. At the end of the two days the contents of these two tubes are decanted off on to a weighted Gooch crucible fitted with an asbestos plug filter, the contents of the second tube being passed through the filter first. The asbestos filter shall be made of ignited long fiber amphibole, packed in the bottom of a Gooch porcelain crucible to a depth of about one-eighth of an inch. The residue in the second tube is then treated with about 2 c.c. of carbon disulphide, care being exercised to disturb it as little as possible, the treatment merely being to remove the small portion of solvent containing bitumen. The Gooch crucible is then washed with clean carbon disulphide until the filtrate is colorless. The crucible and the two tubes are then dried at 225° F., and weighed. The filtrate containing the bitumen is evaporated and the bituminous residue burnt, and the weight of

the ash added to that left in the two tubes and Gooch crucible. The sum of these weights deducted from the weight of the substance taken gives the weight of the bitumen extracted.

It is further recommended by the Committee that the above method be used to determine the amount of bitumen of asphalt paving materials soluble in naphtha. The character of the naphtha to be used is left to the analysts, but it is the recommendation of the Committee that in giving the per cent. soluble in naphtha that it be described by giving the temperatures between which it distils and its specific gravity.

In addition to this the Committee has agreed upon a method for sizing and separating the aggregate in asphalt paving mixtures. The method consists of passing the mineral aggregate through several sieves of the following sizes:

	Inches in diameter.
10 mesh per linear inch, size of wire	.027
20 mesh per linear inch, size of wire	.0165
30 mesh per linear inch, size of wire	.01375
40 mesh per linear inch, size of wire	.01025
50 mesh per linear inch, size of wire	.009
80 mesh per linear inch, size of wire	.00575
100 mesh per linear inch, size of wire	.0045
200 mesh per linear inch, size of wire	.00235

It has further been agreed that the consistency, or penetration, of a bitumen, shall be the distance expressed in the 1-100ths of a centimeter that a No. 2 needle will penetrate into it at 25° C. (77° F.), under a weight of 100 grams in five seconds of time, the needle to penetrate direct without friction.

The Committee also desires to state that several investigations relating to its work have been carried on during the past year, on which it hopes to report in the near future.

Submitted on behalf of the Committee:

LOGAN WALLER PAGE,
Chairman.

ARTHUR N. JOHNSON,
Secretary.

REPORT OF COMMITTEE I ON REINFORCED CONCRETE.

In pursuance with the policy adopted and reported at the last meeting of the Society, your Committee has not taken the initiative in the investigation of concrete and reinforced concrete, but has heartily cooperated in the execution of the programme agreed upon by the members of the special committees composing the Joint Committee on Concrete and Reinforced Concrete.

The work accomplished during the present year will, for the sake of convenience, be grouped as follows:

(*a*) Work done by the Joint Committee.

(*b*) Work done by the United States Geological Survey.

(*c*) Work done by other technological laboratories.

The work accomplished by the Joint Committee is not in shape for presentation at this time. It consists of the collation of existing literature and the results of previous investigations and, when complete, will constitute a very valuable bibliography.

Results of the tests made in the laboratories of the technological institutions during the year ending June 30th, 1905, have been collated and are now being considered finally by the Sub-Committee on Tests of the Joint Committee on Concrete and Reinforced Concrete.

In general it may be stated that these tests, while not accomplishing all that had been hoped, have cleared up many important points, and have yielded information of considerable value.

They have also been of inestimable value in indicating the difficulties to be overcome in carrying on such investigations, and in pointing out new fields of investigations.

The work under the direction of the United States Geological Survey, in co-operation with the Joint Committee, has been fairly inaugurated and facilities and equipment have been provided for the extension of the work on a much more elaborate scale.

It may be stated that with the two small appropriations provided for the fiscal year ending June 30th, 1906, the investigations now pending include:

1. The examination of the materials from different parts of the country as to their extent and suitability for use in cement mortars and concretes, covering the various

sands, gravels, cinders, slags, etc., and tests made on them to determine the weight, strength, durability and other features which concern their adaptability for use in building construction.

2. Tests of plain and reinforced concrete composed of different aggregates, studying the effect of number, form, size and position of the reinforcing bars for intervals of 30, 90, 180 and 360 days. These tests will be supplemented by tests of the properties of the cement, sand, stone and steel used.

3. Tests of the fire-resisting properties and proper methods for water-proofing cement mortars and concretes.

The Sub-Committee on Tests of the Joint Committee has arranged for investigations at technological institutions as follows:

Columbia University: Effect of heat upon the properties of concrete, especially as regards the compressive strength.

Purdue University: Effect of bending rods. Effect of the elastic limit of steel.

University of Illinois: Effect of the quality of concrete. Effect of the position of the load.

University of Wisconsin: Comparison of large and small beams. The effect of high carbon steel. Short beams.

The Joint Committee instructed its Sub-Committee on Tests to formulate a definite policy to govern its work, which was reported to, and was approved by, the Joint Committee on December 12th, 1905. Copy of this report is appended.

It is expected that the work of collating existing literature, and the results of previous investigations, will be completed by the end of the present year.

The vigorous prosecution of the work by the United States Geological Survey will be possible with the ample funds which Congress has provided for the purpose.

In conclusion, your Committee feels that it will probably be able to report much greater progress at the next annual meeting.

Submitted on behalf of the Committee:

RICHARD L. HUMPHREY, *Secretary.* F. E. TURNEAURE, *Chairman.*

Appendix I.

REPORT OF SUB-COMMITTEE ON TESTS TO THE JOINT COMMITTEE ON CONCRETE AND REINFORCED CONCRETE.

In compliance with the resolution adopted by the Joint Committee on Concrete and Reinforced Concrete at the meeting held in New York on October 11, 1905, your Sub-Committee on Tests desires to present the following report as to the policy to govern the future work of the Joint Committee, together with a program of the investigation they propose making, with subdivisions, and the plan of execution.

The Joint Committee on Concrete and Reinforced Concrete was appointed, primarily, for the purpose of providing through the various societies represented, definite information concerning the properties of concrete and reinforced concrete, and to recommend factors and formulæ required in the design of structures in which this material is used. While the Joint Committee has thus far accomplished little toward formulating a report, it has, nevertheless, acquired a definite knowledge of the work such a report demands.

The tests made prior to the appointment of the Committee were scattered and somewhat fragmentary, and while yielding information of considerable value, the limited scope of the work, lack of uniformity of conditions and methods, and failure to properly report details concerning tests or to complete the investigations, render the results insufficient for the formulation of a report. The Committee, therefore, decided that it was desirable to conduct tests along certain lines. Until recently the only channels open to the Committee for conducting such investigations were the laboratories of the technological institutions, and, perhaps, a few others.

At the meeting of the Joint Committee held during the International Engineering Congress at the World's Fair, St. Louis, in October, 1904, the Sub-Committee on Tests, was instructed to inaugurate investigations at such technological institu-

tions and other laboratories possessing the requisite facilities as would undertake the work. Accordingly, during the last school year, tests were made under this Committee's direction in the laboratories of some twelve engineering schools. The results have been reported to the Sub-Committee on Tests, and the compilation is nearly ready for presentation to the Joint Committee. The plan adopted by the Joint Committee involved direction and inspection of this work by the Sub-Committee on Tests. This the Committee was unable to do through lack of funds with which to pay the expenses of inspectors and other assistants.

It might also be stated that the first year's work would naturally be of a preliminary nature, which would serve to develop essential points to be observed and the provisions to be made in future tests. Naturally, the conditions under which these tests were made, and the personal equations of those making the test pieces, and the ideas of those supervising the tests, were widely at variance, and the results, while possessing value, are not fully comparable and must be studied individually.

About March of the present year a small appropriation was made to the United States Geological Survey for the investigation of structural materials.

In the determination of the manner in which this money should be expended it was deemed advisable to create for the purpose a National Advisory Board on Fuels and Structural Materials. A number of the members of the Joint Committee were appointed members of this Advisory Board, and through their influence the money was devoted to the investigation of cement mortars and concretes.

At the meeting of the Joint Committee in Cleveland, on June 21, 1905, it was decided to co-operate with the United States Geological Survey, and the Committee's representatives on the Government Advisory Board were requested to advise as to the plan for this co-operation.

At the meeting of the Committee held at Atlantic City, on June 30, 1905, a formal plan of co-operation was adopted by which the program of the Sub-Committee on Tests was to be carried out in the Government laboratories. These laboratories known as the "Structural Materials Testing Laboratories," have been organized and are under the direction and supervision

of the present Chairman of the Sub-Committee on Tests. It was also decided to conduct investigations at such institutions as the Sub-Committee on Tests might elect, under the direction of the Committee and the inspection of the representative of the Government laboratories. Accordingly, arrangements have been made for carrying on tests at the Universities of Illinois, Purdue and Wisconsin and, possibly, Columbia. These tests consist of determinations of the effect, at different ages, of varying percentages of round, square and flat bars of steel of different elastic limit, using the same concrete; of the bond under similar conditions; of the properties of tee-beams; of the effect of loading beams centrally, and at 2, 4 and 8 points; of the shearing strength of concrete; of the tensile strength and modulus of elasticity of concrete in tension in length of 12 feet; of the effect of different methods of reinforcing a beam for diagonal tension.

POLICY OF COMMITTEE.

The policy of the Joint Committee, up to the present time, has lacked definiteness. It is evident that, to secure efficiency the Committee must adopt a policy to govern its future work.

It is apparent that it would be desirable to conduct a comprehensive series of experiments in one laboratory where the conditions, methods and personal equations of those making the test pieces and the ideas of those supervising the tests are more nearly constant. Thus comparable results would be obtained, giving the uniformity and consistency necessary for the development of essential underlying principles, and which could not be expected under the conditions prevailing at different places and under the guidance of different persons, as would be the case at different technological institutions.

The Committee would, by this means, obtain ultimately, as a basis for its report, a complete and thorough series of tests made by the same squad of experienced observers acting under the direct supervision of those having both the ability to judge of the thoroughness and reliability of the work and the necessary time to devote to its supervision.

The wide area over which the technical schools are scattered renders the expense of providing uniform materials and of inspect-

ing the preparation of the test pieces and the execution of tests very great. Besides, the work cannot generally be carried on uniformly throughout the year, but must be concentrated into a few months. This is a serious difficulty in any series of tests.

However, in the progress of these investigations, there will necessarily be considerable experimental work in opening up certain phases of a problem, as, for example, the study of proper methods to be followed, the sources of error to be guarded against, the probable cause of a given phenomenon, that would be of material help in planning the work, or in corroborating the results of other tests; and it would seem wise to secure the co-operation of the technical schools, utilizing their facilities to the extent indicated, in carrying on investigations.

The entire Joint Committee has been divided into a number of sub-committees for the purpose of collating existing literature and the results of previous investigations. These results, when compiled, will serve, with the recommendation of each Committee, as a guide in formulating the future work of the Joint Committee. The results of the compilations of the various sub-committees shall be turned over to the Sub-Committee on Tests for their consideration and to be reported by them to the Joint Committee. If it is found that there is a reasonable concordance in certain lines, it would seem undesirable for the Sub-Committee on Tests to plan more than a few confirmatory experiments. In those lines where there is no agreement, the Committee work must necessarily be more extensive in order to be conclusive.

The following is a suggested program of the investigations to be made by the Joint Committee, from which a schedule is to be prepared as the tests progress:

PROPOSED PROGRAM FOR THE INVESTIGATION OF CONCRETE AND REINFORCED CONCRETE.*

I. *Examination and Classification of Constituent Materials:*—Sands, gravels, stones, gravel and stone screenings ($\frac{1}{4}$-inch screen), slags, cinders, etc., to be collected by a special representative of the Testing Laboratory sent out for that purpose.

*Approved by National Advisory Board on Fuels and Structural Materials at the meeting held at Washington, D. C., March 31, 1906.

A. EXAMINATION OF DEPOSIT

as to the extent and nature of the material from which the samples are collected.

B. PHYSICAL TESTS IN THE LABORATORY:

1. Mineralogical examination,
2. Specific gravity,
3. Weight per cubic foot,
4. Sifting (granularmetric composition),
5. Percentage of silt and character of same,
6. Percentage of voids,
7. Character of stone as to percentage of absorption, porosity, permeability, compressive strength and behavior under treatment.

C. CHEMICAL ANALYSIS

as to the character of the stone, silt, etc., used in tests.

II. *Tests and Classification of Mortars* made with typical Portland cement and sand, gravel and stone screenings ($\frac{1}{4}$-inch screen). Proportions to be stated by weight and volume. Unit of volume for cement, 100 lbs. per cubic foot. The typical Portland cement to be prepared by thoroughly mixing a number of brands, each of which must meet the following requirements:

Specific gravity, not less than 3.10.

Fineness, residue not more than 8 per cent. on No. 100 or 25 per cent. on No. 200 sieve.

Time of setting:

Initial set, not less than 30 minutes;
Hard set, not less than 1 hour or more than 10 hours.

Tensile strength:

Neat,
24 hours in moist air.....175 lbs.
7 days (1 day in moist air, 6 days in water).....500 lbs.
28 days (1 day in moist air, 27 days in water).....600 lbs.

One part cement, 3 parts standard Ottawa sand:
7 days (1 day in moist air, 6 days in water).....175 lbs.
28 days (1 day in moist air, 27 days in water).....250 lbs.

Constancy of volume:

Pats of neat cement 3 inches in diameter, ½ inch thick at center, tapering to a thin edge, shall be kept in moist air for a period of 24 hours:

A. A pat is kept in air at normal temperature and observed at intervals for at least 28 days.

B. Another pat is kept in water maintained as near 70 deg. F. as practicable and observed at intervals for at least 28 days.

C. A third pat is exposed in an atmosphere of steam above boiling water in a loosely closed vessel for 5 hours.

These pats must remain firm and hard and show no signs of distortion, checking, cracking or disintegration.

The cement shall not contain more than 1.75 per cent. anhydrous sulphuric acid or more than 4 per cent. magnesium oxide.

A test of the neat cement must be made with each mortar series for comparison of the quality of the typical Portland cement.

A. PHYSICAL TESTS IN LABORATORY:

1. Tensile strength with one part cement to varying percentages of material under test, for 7, 28, 90, 180 and 360 days;
2. Compressive strength with one part cement to varying percentages of material under test, for 7, 28, 90, 180 and 360 days;
3. Transverse strength with one part cement to varying percentages of material under test, for 7, 28, 90, 180 and 360 days;
4. Shearing strength with one part cement to varying percentages of material under test, for 7, 28, 90, 180 and 360 days;

5. Tensile strength with cement, material sieved to one size, for 7, 28, 90, 180 and 360 days;
6. Compressive strength with cement, material sieved to one size, for 7, 28, 90, 180 and 360 days;
7. Transverse strength with cement, material sieved to one size, for 7, 28, 90, 180 and 360 days;
8. Shearing strength with cement, material sieved to one size, for 7, 28, 90, 180 and 360 days;
9. Modulus of elasticity in compression of different mixtures as to proportion and size of the aggregate, for 30, 90, 180 and 360 days;
10. Modulus of elasticity in tension of different mixtures as to proportion and size of aggregate, for 30, 90, 180 and 160 days;
11. Yield in mortar;
12. Porosity;
13. Permeability;
14. Volumetric changes in setting;
15. Absorption;
16. Methods of waterproofing;
17. Freezing tests;
18. Coefficient of expansion;
19. Effect of oil:
    (*a*) On hardening mortar,
    (*b*) On hardened mortar;
20. Effect of sea water.

III. *Tests and Classification of Concrete* made with typical Portland cement and stone, stone and gravel screenings, gravel, sand, cinder, slags, etc. Proportions to be stated by weight and volume. Unit of volume for cement, 100 lbs. per cubic foot.

A. PHYSICAL TESTS IN LABORATORY:

1. Tensile strength with different mixtures as to proportion and size of the aggregate, for 30, 90, 180 and 360 days;
2. Compressive strength of different mixtures as to proportion and size of aggregate, for 30, 90, 180 and 360 days;

3. Transverse strength of different mixtures as to proportion and size of aggregate, for 30, 90, 180 and 360 days;
4. Shearing strength with different mixtures as to proportion and size of aggregate, for 30, 90, 180 and 360 days;
5. Modulus of elasticity in compression of different mixtures as to proportion and size of the aggregate, for 30, 90, 180 and 360 days;
6. Modulus of elasticity in tension of different mixtures as to proportion and size of aggregate, for 30, 90, 180 and 360 days;
7. Character crushed stone used:
   (*a*) Weight per cubic foot,
   (*b*) Size,
   (*c*) Percentage of voids,
   (*d*) Percentage of silt;
8. Weight per cubic foot, uncrushed;
9. Yield;
10. Absorption;
11. Porosity;
12. Permeability;
13. Methods of waterproofing;
14. Protective influence against corrosion of metal;
15. Fire resisting qualities:
   (*a*) Effect of heat on hardening concrete,
   (*b*) Effect of heat on hardened concrete,
   (*c*) Thickness necessary for proper insulation.
16. Freezing tests;
17. Volumetric changes;
18. Effect of vibration and of applied stress (impact):
   (*a*) On hardening of plain and reinforced concrete,
   (*b*) On hardened plain and reinforced concrete;
19. Adhesion of concrete to metal under varying conditions, for varying periods, up to at least three years:
   (*a*) Effect of shape,
   (*b*) Effect of embedded length,

(*c*) Effect of various kinds of loading,
(*d*) Effect of chemical action,
(*e*) Relative value of surface adhesive resistance and grip;

20. Effect of oils:
    (*a*) On hardening concrete,
    (*b*) On hardened concrete;
21. Coefficient of expansion;
22. Effect of sea water.

B. FULL SIZE TESTS:

1. Beams of various spans, sections and compositions;
2. Building blocks and bricks, as to:
    (*a*) Compressive strength, wet and dry mixtures,
    (*b*) Transverse strength, wet and dry mixtures,
    (*c*) Shearing strength, wet and dry mixtures,
    (*d*) Absorption, wet and dry mixtures,
    (*e*) Permeability,
    (*f*) Methods of waterproofing,
    (*g*) Effect of accelerating the hardening of concrete blocks by means of live steam, etc.,
    (*h*) Fire resisting qualities,
    (*i*) Efflorescence.

IV. Tests of Reinforced Concrete:

A. BEAMS:

1. Effect of amount of reinforcement,
2. Effect of character of reinforcement,
3. Effect of form, size, and position of reinforcing bars,
4. Effect of initial stress in reinforcement,
5. Effect of different manners of loading,
6. Methods of providing for diagonal stresses,
7. Effect of variation in section, such as trapezoidal, tee-shaped, etc.,

8. Effect of variation in length and depth,
9. Effect of restraining the ends,
10. Effect of repetitive loading.

B. COLUMNS:

1. Effect of amount of reinforcement,
2. Effect of disposition of reinforcement:
   (*a*) Longitudinal,
   (*b*) Hooped,
   (*c*) Combination of (*a*) and (*b*),
3. Effect of form, size, and position of reinforcement,
4. Effect of character and eccentricity of loading,
5. Effect of variation in section, such as square, round and rectangular,
6. Effect of fixing the ends.

C. SLABS:

1. Supported at two or four edges,
2. Fixed at two or four edges,
3. Use of expanded metal, wires, etc.,
4. Effect of concentration of load,
5. Variation in per cent. of reinforcement,
6. Variation in span and thickness.

D. ARCHES:

1. Continuous ring,
2. Hinged,
3. Voussoirs,
4. Shape,
5. Span and rise.

As regards the work in the technological institutions, it is recommended that there be taken up, in a limited number of schools possessing the proper facilities, investigations comprising, in parts, tests in which the methods of execution are still open to formulation and which involve general phenomena. In addition to this, it is recommended that the Sub-Committee on Tests be authorized to offer its services in an advisory capacity to any laboratory conducting investigations of this character. The following list is suggested as available at present:

1. Shearing—Comparison of methods;
2. Modulus of elasticity—Comparison of methods;
3. Protective influence of concrete against corrosion;
4. Fire resisting qualities of concrete;
5. Methods of waterproofing;
6. Coefficient of expansion;
7. Effect of vibration and applied stress;
8. Adhesion of concrete to metal;
9. Reinforced concrete beams;
   (*a*) Effect of different manners of loading,
   (*b*) Methods of providing for diagonal stresses,
   (*c*) Effect of variation in section,
   (*d*) Effect of restraining ends,
   (*e*) Amount and charaeter of reinforcement;
10. Reinforced concrete columns—Method of testing.

The direction of all this work is to be under the Sub-Committee on Tests, as provided in the rules of organization.

SUMMARY OF RECOMMENDATIONS.

The following is a summary of recommendations:

1. A comprehensive series of tests to be conducted under the direction of the Sub-Committee on Tests at some point in co-operation with the United States Geological Survey.
2. The co-operation of the technological schools in tentative or general experimental work under the direction of the Sub-Committee on Tests.
3. The collation of existing literature and results of previous experiments by sub-committees of the Joint Committee, to be reported to the Sub-Committee on Tests for its consideration, and to be reported by them to the Joint Committee.

The Sub-Committee on Tests has endeavored to outline a definite policy from which it may be reasonably expected to derive the requisite data for the formulation of its final report.

Each member of the Joint Committee should be willing to

render all possible assistance in carrying out the program, and the Sub-Committee on Tests would further emphasize the fact that, unless the Joint Committee takes hold of the work in a vigorous manner and provides ample funds for the purpose, the Joint Committee had better be disbanded.

The Sub-Committee on Tests cannot emphasize too strongly the vital importance to the engineering profession of the results to be derived if the program proposed be carried out in an efficient manner.

Submitted by the Sub-Committee on Tests,

RICHARD L. HUMPHREY,
Chairman.
W. K. HATT,
OLAF HOFF,
SPENCER B. NEWBERRY,
GEORGE F. SWAIN
A. N. TALBOT.

REPORT OF COMMITTEE J ON STANDARD SPECIFICATIONS FOR COKE.

Your Committee begs to report progress. During the past year a set of tentative specifications governing the sale of foundry coke has been prepared and circulated for comment and criticism. The results of this were brought before the Committee, fully discussed, and the following decided upon:

It seems that for several years a change has been gradually taking place in the coke situation of the country. A number of new fields are being drawn upon for coke-making purposes and in addition new methods of operation are being applied. The result is that the so-called standard 72-hour coke made in the old bee-hive oven is no longer descriptive of what is being shipped under this name, and the best looking portions of every charge are put aside for foundry purposes and shipped as the 72-hour article. As the results obtained in the foundry with 48-hour, or even 24-hour coke thus selected, are equal to those from the straight 72-hour variety, it would seem desirable to eliminate this deceptive provision from specifications.

The advent of by-product coke in the foundry industry has further modified the existing conception of what a foundry coke should look like, and hence your Committee feels that in this time of transition it would be unwise to put forth a definite specification based entirely on experience with the Connellsville district, at least until further studies in connection with the production of coke have been made, thus doing justice to the maker as well as the consumer.

These additional studies may be summarized as follows:

Investigations covering the proper sampling of coke. All the specifications in the world will be useless unless a properly representative sample is obtained.

Next the chemical analysis of coke. This is to include what is wanted in the examination as well as the preparation of standard methods for determining the separate constituents. Thus the question of moisture determination, the total sulphur, the sulphur

in the ash and the effect the latter is supposed to have on the iron under varying melting conditions.

Next come the physical tests of coke. Just what is required along this line, and what may be omitted. Thus, a moment of thought will show how worthless the crushing strength of a cube, cut from a lump is for representing a shipment. Or for that matter, 100 such cubes, no two pieces of the various parts of a charge being alike.

Finally a study should be made of the behavior of coke under what may be called service tests; that is to say the devising of methods showing how it would behave in descending the cupola or blast furnace. Also just what happens to a coke in being unloaded several times with a fairly high drop, etc.

All these matters enumerated above will naturally form the basis of a set of specifications which will give a positive assurance to the purchaser that whatever he does with the coke he buys, good results are possible when the specifications have been met.

Your Committee has further been promised the active co-operation of the Government Fuel Testing Bureau in this work, and as the investigations will be equally valuable to blast furnace and smelter, we respectfully request the American Society for Testing Materials through its Executive Committee to enlarge the scope of our work by striking out the word *Foundry* in the title of our Committee, making it read: *On Standard Specifications for Coke.**

This will enable us to include the representatives of many metallurgical industries in our Society, and much good must come to the country as a consequence. A series of coke specifications can thus be worked out for foundry, furnace, and smelter, which will assist in improving methods of making this important article of commerce in the various coal fields, now being heavily drawn upon.

Respectfully submitted on behalf of the Committee,

C. H. ZEHNDER,
Chairman.

RICHARD MOLDENKE,
Secretary.

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* This change has been made by authority of the Executive Committee.—ED.

DISCUSSION.

MR. RICHARD MOLDENKE.—There is a feeling abroad in the country that the coke situation is undergoing a change. Our committee had a set of tentative specifications prepared as suited to ordinary foundry conditions. The discussion in committee, however, developed the fact that to wait a little would be good policy. We have in this country some five thousand five hundred foundries using coke of some kind. Five hundred of these would go to the trouble of experimenting to get the best possible results with the coke most suitable in regard to cost, quality and reliability in shipments. The other five thousand would have to be educated. or rather handed definite results and instructions for their guidance. For that reason we should have some discussion on the different classes of coke, and their mode of manufacture. **Mr. Moldenke.**

There was a time, during the last two years, when coke was very difficult to obtain. I know of cases where I was called in to help out, in which the sulphur content actually ran up to 3.25 per cent. One would come to the conclusion that owing to strikes, the scarcity of coal, and the consequent high price, the mines were being cleaned up, and everything shipped that looked black. The result was that the iron suffered fearfully, and the makers of the by-product article were enabled to come into the market and have their coke tried. For instance, the New England foundrymen took up by-product coke instead of that obtained from long distances, and are to-day continuing its use.

When I made the first set of coke tests at the U. S. Fuel Testing Plant in St. Louis, I tried Connellsville and by-product coke side by side in comparison with the cokes made at the plant from hitherto untried coals. The results were very gratifying. The Connellsville coke worked no better than the by-product material, and the other cokes showed very interesting results. A second set is now being run through by Mr. Belden, of the U. S. Geological Survey, and the indications are that the country will soon be using cokes properly made near at home, instead of receiving their fuel from long distances.

REPORT OF COMMITTEE K ON STANDARD METHODS OF TESTING.

Some of the Sub-Committees have made considerable progress in their work which has been reported to the full Committee.

The only result which has been reduced to such form as to warrant publication in the Proceedings of the Society is the circular letter of inquiry addressed to various testing laboratories in different parts of the world. These questions are presented below. When these circular letters have been sent out and a sufficient number of replies have been received, the work will progress more rapidly.

Respectfully submitted on behalf of the Committee,

GAETANO LANZA, *Chairman.*

CIRCULAR LETTER OF INQUIRY.

DEAR SIR:—

The Committee upon Standard Methods of Testing of the American Society for Testing Materials, desires, as an aid to its work, to obtain from the various Laboratories and Works where materials are tested certain information regarding the methods pursued by them, in testing steel, wrought iron, cast iron, and other metals.

The Committee consists of the following, viz:—Gaetano Lanza (Chairman), W. A. Bostwick, James Christie, Charles B. Dudley, W. K. Hatt, Henry M. Howe, A. P. Hume, Richard L. Humphrey, Mansfield Merriman, Richard Moldenke, E. D. Nelson, H. P. Talbot, Geo. E. Thackray, H. V. Wille, and Ira H. Woolson, all members of the American Society for Testing Materials.

Will you kindly furnish this Committee with such information as you can, regarding the methods pursued in your Laboratory, both in the case of tests made for commercial purposes, and in the case of those made for purposes of investigations, including copies of any blanks which you are in the habit of using. The subjects upon which this Committee desires such information are enumerated below.

I. TENSILE TESTS.

1. What are the forms, dimensions, mode of selection, and mode of preparation of the standard tensile test specimens employed by you?
2. What are the kinds, and capacities of the various testing machines employed by you? In the case of testing machines whose readings are affected by piston or plunger friction, how do you make the suitable corrections?
3. What, if any, is your mode of calibrating your testing machines? With what frequency?
4. What methods do you pursue in measuring elongations, including the kinds of extensometers employed, the mode of attaching them to the test specimens, the number and location of the points of contact between the extensometers, and the specimens; the limits of accuracy obtained in the readings, and in the results, when they are used for the determination of moduli of elasticity, elastic limit, yield point, etc., as well as when used for the determination of ultimate elongations? What is your method of measuring the ultimate elongations of the usual commercial test specimens with eight-inch gauged length?
5. What kind of grips do you employ for holding the specimens in the testing machines, and what are the effects of different grips on the results?
6. What is the speed of applying the load generally employed by you and the effects of using different speeds?
7. When testing eyebars, connecting rods, or other full size pieces in tension, what are the methods pursued by you regarding the various matters enumerated above?
8. In testing cast iron in tension are the specimens pulled in the rough or in the turned section? What is the ratio between the diameter of the rough and the turned section? What kind of grips are used?

II. COMPRESSIVE TESTS.

1. Has your laboratory made compressive tests of wrought iron and steel, and, if so, what form and size of specimens have you used?
2. What form and size of specimens do you recommend for compressive tests on wrought iron and steel?
3. What form and size of specimens have you used for compressive tests of cast iron?
4. What form and size of specimens do you recommend for compressive tests of cast iron?
5. What kind of bedding, if any, should be used for metallic specimens under compressive tests?
6. At what rate should the load be applied in compressive tests of metals?
7. What are the best methods for determining elastic limit, and modulus of elasticity in compressive tests of metals?
8. Information regarding the best methods of conducting compressive tests of copper, brass, bronze, and other metallic substances is also desired.
9. What limit of deformation, or what load, do you regard as an index of strength of metals in compression?
10. What form and size of compression specimens should be used when measurements of the lateral increase are to be made?
11. What methods do you pursue in the testing of columns, connecting rods, or other full size pieces in compression?

III. TRANSVERSE TESTS.

1. For what purposes, and in what cases do you employ any standard transverse test specimens?
2. What are the forms, dimensions, manner of loading, and speed of application of the load, which you employ in case of such standard transverse test specimens?
3. What measurements of deformation do you make, and what are the methods pursued in making them,

and what is the degree of accuracy with which the modulus of elasticity, the elastic limit, etc., is obtained by your methods?

4. With what degree of accuracy is the modulus of rupture, in the case of ductile metals, obtained by your methods, in transverse test specimens?
5. What methods do you employ when testing full size beams, or other full size transverse test specimens?

IV. IMPACT TESTS.

1. Has your laboratory made any tests under impact?
2. For what purposes are these tests performed?
3. What type of machine is used? (*a*) Weight of hammer. (*b*) Free fall. (*c*) Weight of anvil. (*d*) Method of guiding hammer. (*e*) Method of release. (*f*) If anvil is supported on springs, state weight and size. (*g*) Nature of the recording device. (*h*) Nature of the foundations.

   If possible submit drawings of machines.
4. What kinds of tests are performed?
5. State forms, dimensions and manner of support of test pieces. Describe any cushion blocks employed in the cases of the various tests.
6. Manner of conducting tests. (*a*) One blow, or a number of blows. (*b*) Fixed height, or increasing height of drop. (*c*) Is flexure specimen turned over between blows? (*d*) Is it permissible to interrupt tests?
7. What measurements of deformation or rupture work are made: and what methods are pursued in making them?
8. Has the machine in use been calibrated?
9. Are tests made at all temperatures? Are the test pieces warmed in winter?

V. METALLOGRAPHIC TESTS.

1. Are you making any microscopic examinations regularly, for the current testing of your steel, as distinguished from occasional tests for special purposes?

2. What lines of microscopic examination do you find most practical, and profitable?
3. In determining the grain size, what reagent do you use, and what strength do you use, and for what length of time is it applied, and what magnification do you find most convenient?
4. The same questions with regard to sorbitic structure.
5. What microscope do you find best for direct examination, and what for photographic purposes?

VI. REPEATED STRESS.

If you make tests of metals subjected to repeated, or to alternate stresses, kindly give an account of the methods pursued.

VII.

Any suggestions on related matters not embraced in the above will be appreciated.

Very respectfully,

GAETANO LANZA,
Massachusetts Institute of Technology,
Boston, Mass., U. S. A.,
Chairman of Committee on Standard Method of Tests.

REPORT OF COMMITTEE L ON STANDARD SPECIFICATIONS AND TESTS FOR CLAY AND CEMENT SEWER PIPES.

The Committee selected by you was organized for its first meeting, held September 6, 1905, at the office of the Secretary, in New York City, and has since had meetings almost every month. At these meetings the preliminaries were discussed regarding the scope of the work to be done and the methods of testing which were employed in various places in America and Europe. These discussions had the object of determining, so far as practicable, the present customs, their advantages and defects, as well as the accuracy and reliability of the methods now in use.

A few preliminary tests were also made by us, with the view to standardizing methods. A proper distinction between significant and insignificant defects will be made.

It is proposed to study the published evidence and to carefully consider in connection herewith the work done by other committees and authorities who have considered the same or any allied subject. Of special value at the present time is the result of the preliminary studies made by the Committee on Standard Tests for Clay and Cement Sewer Pipe of the International Society.

Respectfully submitted on behalf of the Committee,

RUDOLPH HERING,
Chairman.

CHAS. F. MCKENNA,
Secretary.

REPORT OF COMMITTEE M ON STANDARD SPECIFICATIONS FOR STAY BOLT IRON.

Owing to the fact that several important points affecting the formation of specifications for staybolts require further investigation, your Committee does not care to submit the specifications proposed last year for a vote of the Society.

It may be of interest to know, however, that several prominent makers of staybolt iron have adopted the method of piling proposed, and by the use of the specification during the past year, at the Baldwin Locomotive Works, it has been shown to be a logical one, and to insure an iron which gives satisfactory service.

Submitted on behalf of the Committee,

H. V. WILLE,
Chairman.

REPORT OF COMMITEE O ON UNIFORM SPEED IN COMMERCIAL TESTING.

Your Committee on Uniform Speed in Commercial Testing herewith takes pleasure to present for your consideration the results of its work during the past year.

Boiler steel plates, bar steel of .15, .31, .45 and .60 per cent. carbon and forgings of tire and axle steel were kindly donated to your Society, for use of the Committee, by Messrs. W. A. Bostwick for the Carnegie Steel Company, C. R. Stewart for the Cambria Steel Company, and A. A. Stevenson for the Standard Steel Works. This material was divided into 437 test pieces and tested in the physical laboratories of the American Locomotive Company, American Steel and Wire Company, Baldwin Locomotive Works, Carbon Steel Company, Carnegie Steel Company, Pennsylvania Railroad Company, Pennsylvania Steel Company, Purdue University, Chicago, Rock Island and Pacific Railway Company, University of Illinois, University of New York and the Westinghouse Electric Manufacturing Company, all of which, through the courtesy and cordial co-operation of the heads of the respective departments, contributed materially to the success of the work of your committee. The test section used for making these tests were those recommended by your Society for steel of boiler grade and forgings. Tables I, II and III give the average of the different classes of materials; 160 tests of .45 per cent. and .60 per cent. carbon steel bars, made at the New York University, formed the basis for a graduation thesis of two graduates of the School of Applied Science.

On analyzing and comparing the details of the results of these 437 tests, we find some difference in results of the same material tested at the same, or nearly the same speed. This is due, apparently, to the differences in testing machines, of the manner of measuring, of personal equation of the operator which plays such a large part in all testing, and finally of differences in the material itself, all of which are factors entering into commercial testing at one time or another, singly or collectively, and cannot be avoided under present conditions. The results of tensile strength

TABLE I.

BOILER STEEL. UNANNEALED.

0.20 per cent. Carbon. Test Section. 1½ in. wide.

Speed per Minute in in.	Thickness of Plates.	Elastic Limit. Pounds per sq. in.	Tensile Strength. Pounds per sq. in.	Elongation in 8 in. Per cent.	Reduction of Area. Per cent.
0.50	½ in.	29,190	56,125	30.7	53.0
0.750		28,310	55,740	29.8	....
1.00		29,859	56,220	32.0	....
1.50		28,194	56,286	30.3	54.9
2.00		33,237	57,424	30.3	52.4
3.00		33,657	57,790	31.5	....
4.00		29,058	57,577	31.8	....
6.00		31,990	59,220	29.8	....

Total number of Tests.....92.

AXLE STEEL. ANNEALED.

Test Section. ½ in. diameter.

Speed per Minute in in.	Original Size of Bar. Diameter.	Elastic Limit. Pounds per sq. in.	Tensile Strength. Pounds per sq. in.	Elongation in 2 in. Per cent.	Reduction of Area. Per cent.
0.0138	1½ in.	38,000	60,750	35.5	53.0
0.457		33,760	62,760	32.7	48.0
4.07		36,760	64,813	30.0	47.0
6.75		34,333	65,500	33.0	42.2

Total number of Tests.....12.

TIRE STEEL. ANNEALED.

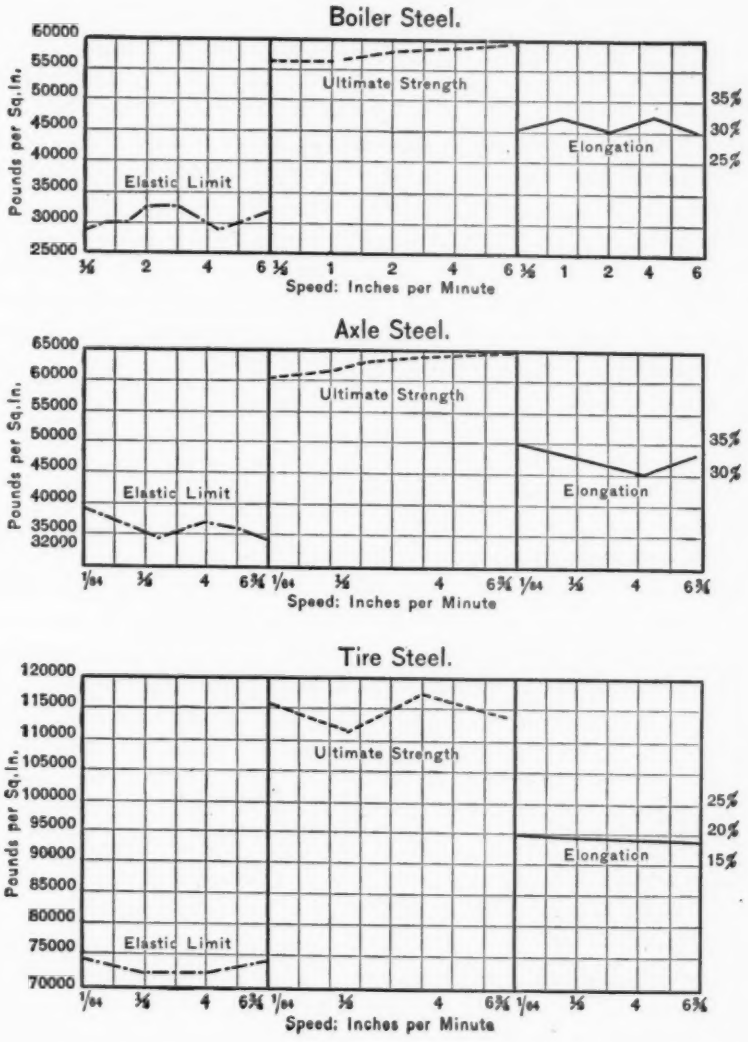
Test Section. ½ in. diameter.

Speed per Minute in in.	Original Size of Bar. Diameter.	Elastic Limit. Pounds per sq. in.	Tensile Strength. Pounds per sq. in.	Elongation in 2 in. Per cent.	Reduction of Area. Per cent.
0.0138	1½ in.	74,000	115,500	20.2	37.5
0.457		73,120	113,300	19.5	35.5
4.07		72,810	117,133	19.2	31.5
6.75		74,000	114,750	19.0	28.2

Total number of Tests.....12.

DIAGRAM I.

Effect of Speed on Strength of Steel in Tension.



and elongation show tolerable uniformity in the twelve laboratories. The same cannot be said of the elastic limit which was taken with the dividers at slow and fast speeds. In some cases, in addition, the drop of the beam was also observed by a separate attendant, either as a check or for personal information. The reasons for this irregularity in results of elastic limit are easily explained by the very nature of the phenomenon which we call the elasticity of metals. Unless one is an expert not only in the mechanical performance of using the dividers, or micrometers, or watching the beams, in taking the elastic limit, and at the same time is familar with the structure and behavior, under stress, of the class of metal he is testing, there is liability of errors, large and small, and the result is nothing but guess work. In boiler steel the highest limit was 31,700 pounds per square inch at a one-inch speed and 29,700 pounds at a four-inch speed. At one laboratory the elastic limit was 300 pounds lower at a half-inch speed than at another laboratory at a six-inch speed. There is a surprising uniformity in the results of elongation at all speeds and all laboratories. The rate of flow, as expressed in per cent. of elongation, seems to be the same at all speeds, proportionate to the degree of hardness of the metal.

The main and only object for which this committee was originally created was to present some tangible conclusions as a basis for the establishment of a safe maximum speed in commercial testing, without restricting any one to use whatever speed he may choose, that is a speed at the maximum and below which the American Society of Testing Materials is willing to say to the engineer that the results of testing at that speed may safely be accepted as a criterion of the quality of the material tested.

Thus far the objection to using faster speeds in commercial testing than has been customary, has been based upon the assumption that at faster speeds the metal is artificially hardened while stretching, to the extent of increasing the strength way beyond the original quality in the material. Upon the same reasoning it was assumed that the elongation, as an exponent of ductility, would decrease the same as we find it to decrease in steel heated and quenched. This assumption has been based upon the application of the theory of an allotropic change in the steel taking place while disruption of the test piece takes place in the

testing machine. In order to sustain the assumption of an allotropic change, with its supposed hardening effects, we have to assume a change in carbon and iron in the test piece, corresponding to critical points Ac1 and Ac2 producing martensite under cold working, as claimed by LeChatelier and not a new constituent as claimed by Carpenter. Thus it is claimed that the effects of pressure, exerted upon the particles by their sliding over each other while the test pieces is being elongated and the metal flows under the stress applied are equal to the effects of hammer hardening when percussive forces are at work to compress the metal into a smaller space and greater density, permitting flow of the metal only after maximum density has been reached, proportionate to the extraneous pressure exerted, evolving at the same time a considerable degree of heat, especially under hammering. Now the theory of an allotropic change in steel, due to cold working, has received the earnest attention of LeChatelier, Osmond, Howe, Arnold, Roberts-Austin and others, and while some agreement has been reached along that line of investigation, due to heating and quenching, there is an inclination to leave the effects of cold working on steel open for discussion, claiming that the effects are simply those due to condensation without change of carbon. The chairman of your Committee, at one time, furnished an investigator with numerous specimens of hard and soft steel, hammer hardened to all stages of density, but no distinct change of carbon was discovered. But even if we admit all that has ever been claimed concerning an allotropic change in steel, due to cold working, the results of the tests made by your Committee do not show that gradual increase in strength and decrease in ductility which we observe as a natural accompaniment of changes of carbon due to heating and quenching. The metal in a test piece while being disrupted by the static force exerted by the testing machine is not subject to percussive forces, is not condensed more than the natural flow of the metal produces, hence is heated but slightly and never to a degree that would change the carbon in the short space of time similar to the carbon changes when the steel is heated to red heat. Moreover, what heat is produced, due to internal friction of the sliding of the particles, is freely dissipated as fast as it is created. Therefore, the engineer may dismiss from his mind the theory of hardening of the test piece

TABLE II.

ROUND BAR STEEL. UNANNEALED.

0.15 per cent. Carbon. Tested in Full Size.

Speed per Minute in in.	Diameter of Bars.	Elastic Limit. Pounds per sq. in.	Tensile Strength. Pounds per sq. in.	Elongation in 8 in. Per cent.	Reduction of Area. Per cent.
3.00	½ in.	.....	62,853	28.5	....
6.00		.....	64,035	28.1	....
0.81	¾	39,675	61,930	27.1	51.3
0.875		26,075	61,370	27.5	51.2
3.00		41,265	65,485	27.0	50.1
3.75		42,380	62,915	28.0	54.1
6.31		41,240	62,975	28.7	51.5
0.75	1	31,345	54,750	34.1	64.4
1.00		35,585	55,910	34.5	66.1
1.30		35,540	55,985	35.5	66.2
1.88		35,690	56,180	34.0	66.3
2.50		32,817	55,927	34.1	65.5
3.00		37,180	56,305	37.0	66.0
0.875	1¼	33,342	55,067	36.6	51.0
1.00		29,960	55,146	36.3	67.0
3.00		42,450	57,840	34.0	....
6.00		41,730	59,100	32.0	....
8.00		37,786	56,430	34.5	65.3
1.00	1½	32,635	54,630	38.7	65.9
8.00		36,638	56,326	38.7	64.5

Total number of Tests.....74.

0.31 per cent. Carbon. Tested in Full Size.

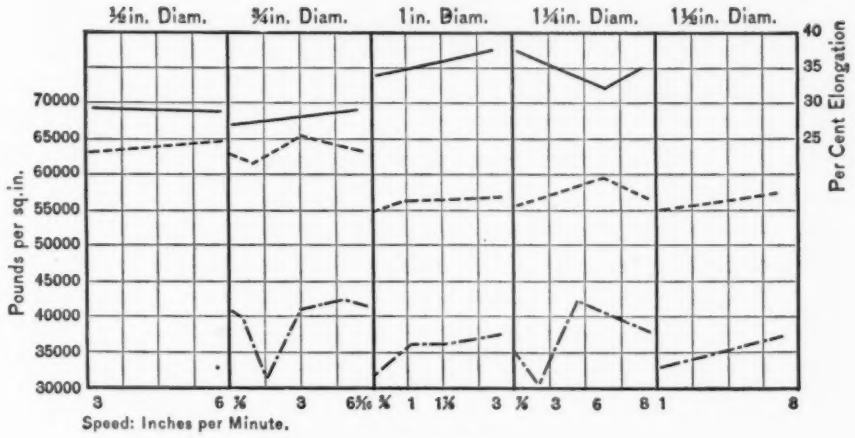
3.00	½ in.	.....	71,928	24.2	....
6.00		.....	72,900	23.6	....
0.81	¾	42,290	67,535	26.0	44.3
0.875		43,417	68,940	25.5	55.3
3.00		41,770	66,060	23.5	49.0
3.75		43,430	70,333	28.0	44.4
6.31		43,762	70,600	25.6	52.1
0.750	1	40,050	64,000	29.7	55.6
1.20		41,010	65,500	30.5	59.0
1.36		39,560	65,120	29.0	53.2
1.87		41,910	66,170	30.0	56.0
2.50		42,600	64,799	30.1	57.8
3.00		41,580	64,540	31.0	52.7
0.875	1¼	38,557	64,600	33.3	57.5
1.00		37,316	64,973	32.5	52.8
3.00		50,100	68,560	24.0	....
6.00		49,870	70,300	25.0	....
8.00		44,543	66,576	32.5	54.7
1.00	1½	35,600	63,146	32.8	52.3
8.00		40,650	64,370	33.1	51.9

Total number of Tests.....74.

DIAGRAM II.

Effect of Speed on Strength of Steel in Tension.

.15 Carbon



.31 Carbon

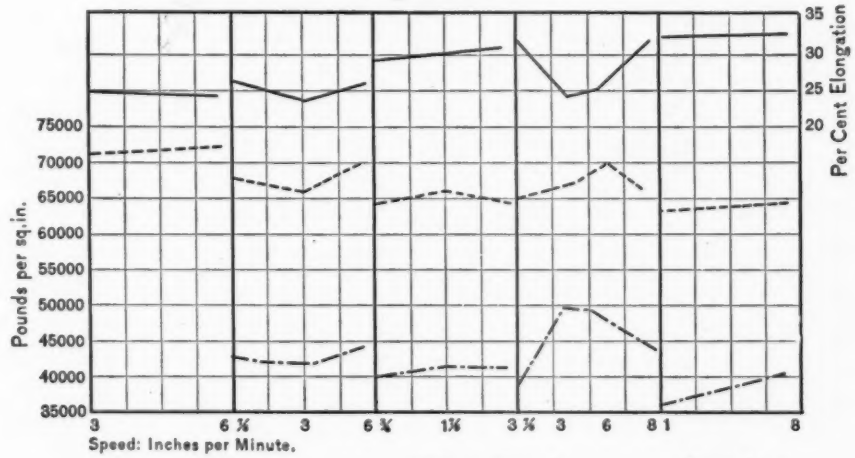


TABLE III.

BAR STEEL. UNANNEALED.

0.45 per cent. Carbon. Test Section. ½ in. diameter.

Speed per Minute in in.	Original Size of Bar. Diameter.	Elastic Limit. Pounds per sq. in.	Tensile Strength. Pounds per sq. in.	Elongation in 2 in. Per cent.	Reduction of Area. Per cent.
0.18	½ in.	65,780	97,500	24.6	42.2
1.375		63,240	99,480	25.7	43.2
3.00		.....	96,920	25.8	....
4.875		65,680	104,240	26.1	43.0
6.00		.....	98,660	26.2	....
0.267	1	57,060	96,435	19.3	42.1
2.75		.....	99,978	20.8	45.4
4.12		.....	99,700	....	....
0.267	1¼	55,930	97,220	....	....
1.12		.....	98,370	....	....
1.84		.....	98,300	19	42.8
2.75		.....	97,420	20.3	46.1
4.12		.....	98,350	19.5	43.5

Total number of Tests.....93.

0.60 per cent. Carbon. Test Section. ½ in. diameter.

0.267	½ in.	80,100	137,470	....	....
1.84		.....	144,510	....	....
4.12		.....	139,320	....	....
0.267	1	76,780	134,850	....	....
1.12		.....	132,500	....	....
1.84		.....	132,610	....	....
4.12		.....	132,500	....	....
0.267	1¼	67,640	131,410	10.6	22.2
1.12		.....	133,200	....	....
1.84		73,470	132,220	9.6	23.1
2.75		.....	133,250	10.3	23.6
4.12		.....	142,670	10.8	19.5

Total number of Tests.....80.

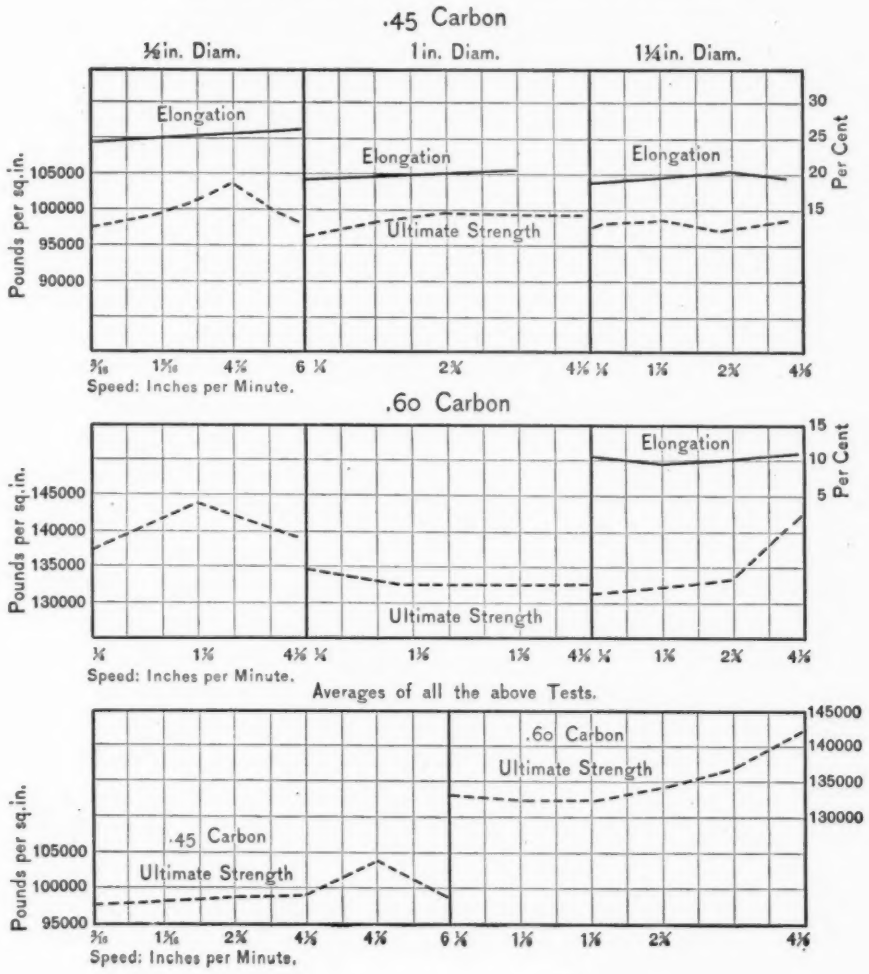
AVERAGES OF ALL THE ABOVE TESTS.

Pounds per square inch.

Speed per Minute.	Carbon 0.45 per cent.	Carbon 0.60 per cent.
0.18	97,500	.....
0.267	96,820	133,210
1.12	98,370	132,850
1.375	99,480	.....
1.84	98,300	132,422
2.75	98,690	134,760
3.00	96,920	.....
4.12	99,050	142,675
4.875	104,240	.....
6.00	98,660	.....

DIAGRAM III.

Effect of Speed on Strength of Steel in Tension.



with increase of speed due to the change of chemical elements. What really does take place, therefore, is simply a slight condensation of the metal in a purely mechanical way without impairment of ability to flow. This slight condensation of the metal, due to the sliding over each other of the particles, produces a slight increase of strength without diminishing of ductility, this slight increase of strength being the last stage of the metal before rupture takes place. The correctness of the above reasoning is demonstrated by the results of tests. With .60 per cent. carbon steel bars we have an average tensile strength of 134,850 pounds with a quarter-inch speed and a tensile strength of 132,500 pounds with a four-inch speed in the same bar. With .45 per cent. carbon steel we have in one series a tensile strength of 97,500 pounds per square inch at a speed of .18 of an inch and 24.6 per cent. elongation and 96,920 pounds and 25.8 per cent. elongation at a speed of 3 inches per minute. The average of 93 tests of .45 per cent. steel is 97,500 pounds at a speed of .18 of an inch and 98,660 pounds at a 6-inch speed, or only 1,100 pounds more, while at a 3-inch speed it is actually less. With the .15 per cent. carbon steel we have, with the $\frac{3}{4}$-inch bar, 61,900 pounds with the .8-inch speed and 62,900 pounds, or only 1,000 pounds more, with the 6-inch speed and 1.6 per cent. elongation more with the fast than with the slow speed. With the $1\frac{1}{4}$-inch bar of .15 per cent. carbon, tested at full size, we have an increase of 1,400 pounds from a $\frac{7}{8}$-inch to an 8-inch speed with a decrease in elongation of 2 per cent. while with the $1\frac{1}{2}$ inch, .15 per cent. carbon bar, tested in full size, we have 1,700 pounds difference between 1 and 8 inches and no difference at all in elongation. With the .31 per cent. carbon bars we have the same phenomenon, a slightly increased strength at the eight-inch speed, and in three instances, a higher elongation at the fastest speeds. In the hard tire steel we have 115,500 pounds and .20 per cent. elongation at a speed of .0138 of an inch and 114,750 pounds or less by 800 pounds and .19 per cent. elongation at a speed of $6\frac{3}{4}$ inches. Taking all these facts and the non-applicability of the allotropic theory into consideration your Committee on Uniform Speed in Commercial Testing recommends the adoption, by the Society, of a maximum speed of three inches per minute for steel of the forging grade, where a 2-inch section is used, and a maximum

speed of six inches for steel of the boiler grade where an 8-inch section is used.

The Committee feels justified in saying that within these limits the results of tests are safe and reliable at the present stage of the steel making.

Concerning the taking of the elastic limit the committee is of the opinion that there should be an agreement that in commercial testing the elastic limit should be taken with the dividers at a slow speed to secure approximate reliability and uniformity of results. The thanks of the Society are due to the authorities of the steel works and universities who, with a highly appreciable courtesy and cordiality assisted your Chairman and the Committee to enable the presentation of this report.

Submitted on behalf of the Committee,

PAUL KREUZPOINTNER,
Chairman.

H. V. WILLE,
Secretary.

DISCUSSION.

Mr. Lanza.

MR. GAETANO LANZA.—I notice that Mr. Kreuzpointner says in the report that in determining the elastic limit, in order to secure uniformity, we should use a slow speed. I should like to ask what he finds as the upper limit of that slow speed, whether the committee fixed on any definite speed that should not be exceeded, in determining the elastic limit.

Mr. Kreuzpointner.

MR. PAUL KREUZPOINTNER.—From the deductions I am able to make from the work of the twelve laboratories, I would say that a $\frac{1}{2}$ or $\frac{3}{4}$ inch speed should be the maximum in taking the elastic limit. A faster speed is liable to lead to error. However, the committee is not prepared to offer any conclusive evidence or definite suggestion on that point.

Mr. Snow.

MR. J. P. SNOW.—In view of the records shown by the committee on the diagrams, especially for the 0.15 and 0.31 carbon steels, and in view of the great irregularity of the elastic limit observed for any speed which is reasonable for commercial testing, it would seem to me that it is entirely useless to determine that feature of the material. It may be remembered that with the specification for material adopted by the Railway Engineering and Maintenance of Way Association, the clause is inserted "The yield point shall be recorded." There is no specification for elastic limit or yield point—which a good many claim to be the same thing—because we deem it useless to record something that is not true. We did say that it shall be recorded, but that was a concession to those who still believe that the elastic limit ought to be found. But my contention is that it does not determine anything; and it seems to me that the experiments on record here, and these diagrams, go to prove that. You have got something, but what is it? It varies, it is not reliable, and it seems to me we are simply deceiving ourselves by pretending to know what the elastic limit is when it is determined in the ordinary way in commercial testing. The speed which Mr. Kreuzpointner recognized as fairly safe for really determining the elastic limit, $\frac{1}{2}$ or $\frac{3}{4}$ inch speed per minute, is probably altogether too slow for ordinary commercial

testing. In fact, he recommends, as I understand his report, a speed of 3 inches, which is all right for elongation and ultimate strength. Now it seems to me that it would be in the line of reason and good practice to eliminate the record of the elastic limit from our ordinary commercial testing of structural steel. I won't say anything about the higher carbon steels. **Mr. Snow.**

MR. KREUZPOINTNER.—In confirmation of what the previous speaker has said, in our observation during the past twenty-five years, as well as those of other laboratories, I was always impressed with the unreliability of the drop of the beam as a determination of the elastic limit. I personally cannot recommend it, since I do not consider it in any way reliable. The dividers are more reliable if the test is made at a slow speed. **Mr. Kreuzpointner.**

MR. EDGAR MARBURG.—It seems to me that it would be rather a radical step to abolish the finding of the yield point altogether. It is undoubtedly true of structural steel as now made, in which the range of ultimate tensile strength is quite moderate, that under a specification which provides that the yield point shall be at least half the ultimate strength; that requirement is easily met, for the yield point is almost invariably higher. Again, while a speed of $\frac{1}{2}$ or $\frac{3}{4}$ inch per minute is very low for commercial testing, in general, it is to be borne in mind that the total deformation, below the yield point is so exceedingly small, amounting to about 0.01 in. in a gage length of 8 inches, and that even after making due allowance for the slipping of the grips, it is a question of only a very short space of time. And if a change be made to a higher speed, beyond the yield point, it does not seem that it will retard the operation greatly to determine the yield point. But to omit finding the yield point is a sort of tacit admission that the elastic limit or yield point is not the life limit of the material. It should surely be found for the higher carbon steels and special steels, where the relation between the elastic limit and ultimate strength is not as definite as in the case of structural steel. But even in the case of the latter the objection on the ground of the addition of time in testing seems to me amounts to very little, in view of the fact that the proposition is to use that speed only up to the yield point. **Mr. Marburg.**

MR. LANZA.—In the report, I think the word "elastic limit" is used almost exclusively. I should like to ask whether the **Mr. Lanza.**

Mr. Lanza. remarks as to speed were meant to apply simply to the elastic limit, or equally to the yield point, or if any distinction was made between the two.

Mr. Kreuzpointner. MR. KREUZPOINTNER.—I recognize very well that the necessity for rapid work has increased to such an extent that we have to waive accuracy in one way or another; and if the engineer is satisfied, then of course the manufacturer ought to be satisfied. The engineer should never deceive himself, however, by thinking that he gets what he wants by the drop of the beam. I have made hundreds of tests in that way, with the drop of the beam and the dividers. There is always an increase, or rather an excess error, of 4,000 to 6,000 or 10,000 pounds for the drop of the beam. Commercial considerations, and the engineer's calculations, may permit of such a variation, but speaking from a scientific standpoint the elastic limit taken by the drop of the beam is not to be recommended.

Mr. Merriman. MR. MANSFIELD MERRIMAN.—In recent years the demand for rapidity in testing has sometimes resulted in omitting the record of elastic limit or yield point. This appears to be a step that is decidedly in the wrong direction, in fact, in a dangerous direction. The reasons assigned for this practice seem to be that it is difficult to obtain the elastic limit by means of dividers, and that there is more or less uncertainty in the determination of the yield point by means of the drop of the beam. But we should not lose sight of the fact that both of these things are matters of importance, and also of the fact that elastic limit and yield point are different things, so that the record of the latter does not give decisive information regarding the former. It is certainly to be desired that the record of a tensile test should include all information possible to be derived from it regarding the material. This result cannot be secured unless an automatic-autographic apparatus is attached to the machine, whereby a diagram may be drawn for each specimen. A fully reliable and convenient apparatus of this kind, requiring little skill in its operation, has not yet been devised. It is hoped that efforts in this direction may be made, at least for steel specimens, the object kept in view being to draw a diagram on a card for each tensile test which shall furnish a complete record regarding modulus of elasticity, elastic limit, yield point, elongation, ultimate strength, and the work expended in the rupture.

MR. W. C. DU COMB, JR.—Representing a manufacturer of testing machines, I would say that the difficulties of obtaining an apparatus which can be placed on every test piece seem to be insurmountable. The time occupied in fastening the autographic device to the specimen prohibits its use for practical testing. Many machines used in technical schools are provided with an autographic or diagram apparatus, and a number of tests are made using this apparatus; but it seems impossible to obtain an instrument with which the yield point can be definitely taken and autographically recorded for commercial testing. In fact it seems to me that Committee O is asking too much of the steel manufacturers to require a pair of dividers to be used to determine the yield point of every specimen. Mr. Du Comb.

An important question is that of standard speeds on testing machines. It would be desirable for testing machine manufacturers to have an expression of opinion from this Society as to the speeds for which a testing machine should be desired. Committee O recommends a maximum speed of 6 inches per minute at the present time. Evidently this is one speed; now if such other speeds as are required are given, the manufacturers can build all commercial testing machines with the speeds specified and a uniformity of speeds on commercial machines will be obtained. If a faster speed than 6 inch per minute is to be required in the near future, it would be desirable to specify the same so that commercial machines can be made accordingly.

At the present time few testing machines have been built which will pull to the capacity of the machine at 6 inches per minute. There are some machines that will pull to 20,000 pounds and possibly 30,000 pounds at 6 inches a minute, and to 50,000 pounds and 60,000 pounds at 3 inches a minute.

I should like to ask if Committee O has made any tests of wrought iron bars showing the effect of different speeds in testing such bars.

MR. KREUZPOINTNER.—During the next year the Committee intends to take up the question of the influence of speed on wrought iron, especially staybolt iron and the finer grades of iron as used now. However, from the experience your Chairman had in testing hundreds of thousands of tons of iron during the last twenty-five years, the question as to the influence of speed has come up several Mr. Kreuzpointner.

Mr. Kreuzpointner.

times, and it is really not very much. From what I know on the subject, I am of the opinion that it is not any more important, if as important, as the influence of speed of testing in the case of steel. But the Committee hopes to present something more definite at the next annual meeting.

I may add that in investigating such questions, I have found, personally speaking, that we have to consider change of physical qualities rather than the chemistry of steel in this question of speed. The heat evolved while a test piece is being broken, I have never found so great that I could not hold the broken piece in my fingers without causing pain. I do not think there is an engineer at this meeting, or in the country, who would be willing to assert that such a low degree of heat, effective during such a short interval of time, as is necessary to pull a test piece, will change the chemical elements of the steel to a degree as to harden the material to any appreciable extent. Consequently, waiving this point, we have to fall back upon the increase in density, caused by the sliding of the crystals over each other, as the source of increase of strength, of what little increase there is, due to testing at the highest speed used by the committee. Considering the structure of steel we can readily see that in this question we have to deal with a physical condition and not with a chemical change.

If the crystals, of which steel is composed, are soft, individually, and the matrix, or so-called homogen iron, in which the crystals are imbedded, is also soft, we have a "mushy" steel of low strength and high ductility and no increase of strength at high speed of testing, because of lack of resistance and density while the metal is forced to flow.

If the crystals are hard and the matrix soft, the crystals will interlock, when sliding upon each other, but will not readily crush upon each other, but rather pass each other for lack of a supporting medium.

But if both the crystals and the matrix are of comparative hardness, then there will be maximum resistance with consequent maximum density and increase of strength of steel under pull.

Thus we find in the varying structures of steel an explanation of the slight increase of strength with harder steels, and no increase with softer steel, at high speeds. While it is admitted that we can destroy the temper of a razor by continued heat, lower than boiling

water, yet in ordinary testing we are neither dealing with such fine, nor tempered material, nor long intervals of time. **Mr. Kreuzpointner.**

Moreover, at the present day nearly all structural steel is of the basic kind and I believe it has been admitted that the structure of basic steel is more open than the structure of acid steel, hence will not become so dense while it is being tested, and therefore is less liable to attain higher strength with high speed of testing. Hence, if we ignore the question of heat producing chemical changes, and consider the question of increase of strength, due to high speed, merely from the physical standpoint, we come nearer to the solution of the problem.

MR. DU COMB.—I should like to move that the Executive Committee be requested to consider the desirability of instructing Committee O to recommend standard speeds for testing machines. **Mr. Du Comb.**

Testing machine manufacturers can change their machines to obtain such speeds as may be recommended without any trouble, the only change required being in the gears. It appears to me that it would be better to take this matter up now than later on, so that in the near future an inspector can go into a testing laboratory and say, "I have pulled material of this kind at such a speed, and therefore I want to use that speed now." Why not fix a standard of speeds as soon as possible instead of delaying till more machines are in use, all having different pulling speeds.

REPORT OF COMMITTEE P ON FIREPROOFING MATERIALS.

In accordance with the outline proposed at the last Convention, your Committee has collated all the available information regarding fire tests on floor constructions both in this country and in England.

Altogether sixty-three tests have been made in this country, of which we have more or less complete record. The detailed information regarding these tests is presented in the tables accompanying this report. This information is as complete as is possible to secure at present, and is obtained from the most authentic sources.

It will be noted that in several instances no information is given except the time and place of the test. In these cases no recorded information was obtainable. These tables represent the sixty-three fire tests made in this country, and seventeen in England.

The tests in America were all made under the supervision of the building authorities in New York City, though some of them were made in conjunction with the building authorities of Philadelphia. The English tests were all made under the immediate direction of the British Fire Prevention Committee.

From a careful study of this data, the Committee would suggest the following outline of a standard test for fireproof floor constructions, with the hope that the same will bring out criticism and discussion in regard to these several provisions, so that at the next Convention the Committee may be prepared to submit a specification.

The test structure may be located at any place convenient to the applicant, where all the necessary facilities for properly conducting the test are provided.

The test structure may be constructed of walls of any material not less than twelve inches thick, properly buttressed on all sides.

The floor construction to be tested shall form the roof of the test structure.

At a height of not less than 2 ft. 6 in., nor more than 3 ft. above the ground level, a metal grate, properly supported, shall be provided, covering the whole inside area of the building.

In the walls below this grate level, draught openings shall be provided, as many as possible, furnishing openings with an aggregate area of not less than one square foot for every ten square feet of grate surface. Means for temporarily closing these openings should be provided.

In the wall, immediately above the grate level, a firing door, 3 ft. 6 in. by 5 ft. high, must be provided in the side of the building at right angles to the floor beams. A second door must be added when the span of the floor slab under test exceeds ten feet.

Flues should be supplied at each of the corners, and oftener in case of a test structure exceeding 250 square feet of grate surface, with sufficient opening to insure a proper draught, securely supported and disposed at the sides of the structure in such manner as not to rest on the floor under test. In no case should a flue area be less than 180 square inches.

The horizontal dimensions of the test structure will depend upon the number and the span of the systems under consideration. The clear span of the floor beams is to be 14 ft. The distance between floor beams, or span of slab, may be varied according to the design of the system to be tested, and should be as near as possible to usual practice. The underside of the construction under test must be not less than 9 ft. 6 in. nor more than 10 ft. above the grate level.

The construction to be tested should be designed for a working load of one hundred and fifty pounds per square foot, and no more. This load to be uniformly distributed without arching effect, and to be carried on the floor during the fire test.

The floor may be tested as soon after construction as desired, but within forty days. Artificial drying will be allowed if desired.

The floor is to be subjected to the continuous heat of a wood fire, averaging not less than 1700° F. for four hours.

The heat obtained shall be measured by means of standard pyrometers, under the direction of an experienced person. The type of pyrometer is immaterial so long as its accuracy is secured by proper standardization. The heat should be measured at not

less than two points when the main floor span is not more than ten feet, and one additional point when it exceeds ten feet. Temperature readings at each point are to be taken every three minutes. The heat determination shall be made at points directly beneath the floor so as to secure a fair average.

At the end of the heat test a stream of water shall be directed against the underside of the floor, discharged through a one and one-eighth inch nozzle, under sixty pounds nozzle pressure, for ten minutes.

After the floor has sufficiently cooled the load on the same shall be increased to six hundred pounds per square foot, uniformly distributed.

The test shall not be regarded as successful unless the following conditions are met: No fire or smoke shall pass through the floor during the fire test; the floor must safely sustain the loads prescribed; the permanent deflection must not exceed one-eighth inch for each foot of span in either slab or beam.

Respectfully submitted on behalf of the Committee,

IRA H. WOOLSON,
Chairman.

R. P. MILLER,
Secretary.

TABLE I.—SUMMARY OF FIRE TES

Kind of Floor.	Date of Test.	Floor.		Test Structure.									Age of Floor.	Duration of Fire.	Av. Temp. °F.
		Span Beam.	Span Slab.	Length.	Width.	Material.	Height Floor.	Firing Doors.	Flues. No.	Flues. Size.	Flues. Height.	Flues. Material			
ROEBLING. Cinder concrete. Segmental.	Sept. 3, 1896.	15′	3′–10½″	15′	11′	Brick.	9′–6″	2	4	15″x15″	.....	.....	33 days	1 hr. 48 min.	1600°
FAWCETT. Terra cotta blocks. I beams. Cinder concrete filling.	Sept. 10, 1896.	14′	.....	14′	11′	"	10′	.....	4	15″x15″	.....	.....	34 days	2 hrs. 43 min.	1988°
CENTRAL. Hollow tile.	Sept. 29, 1896.	14′	4′	14′	11′	"	10′	2	4	15″x15″	.....	.....	31 days	6 hrs.	Fusible Plug. Temp. Melting Iron.
RAPP. Cinder and brick. I beams.	Oct. 26, 1896.	14′	4′	14′	11′	"	10′	1	4	15″x15″	.....	.....	30 days	5 hrs.	1740°
ROEBLING. Cinder concrete. Wire netting.	Oct. 28, 1896.	15′	3′–10½″	15′	11′	"	9′–6″	2	4	15″x15″	.....	.....	32 days	5 hrs.	1779°
THOMSON. Cinder concrete. I beams.	Nov. 7, 1896.	11′	3′–6″	14′	11′	"	10′	2	4	15″x15″	.....	.....	33 days	5 hrs.	1900°
MCCABE. Cinder concrete. Fire proof block. T iron centering.	Nov. 9, 1896.	14′	4′	14′	10′–3″	"	10′	2	4	15″x15″	.....	.....	31 days	5 hrs.	1950°
COLUMBIAN. Cinder concrete. I beams.	Dec. 23, 1896.	14′	4′	14′	11′	"	10	.....	4	15″x15″	.....	.....	30 days	.....	.....
BAILEY. Cinder concrete. Reinforced by tie rods and dovetailed sheet metal.	Jan. 5, 1897.	14′	4′	14′	11′	"	10′	2	4	15″x15″	.....	.....	33 days	5 hrs.	1985°
CLINTON. Cinder concrete. Segmental arches.	Jan. 29, 1897.	14′	4′	14′	11′		10′	2	4	15″x15″	.....	.....	30 days	5 hrs.	1825°
CLINTON. Cinder concrete.	Feb. 11, 1897.	14	4′	14′	11′	"	10′	2	4	15″x15″	.....	.....	43 days	5 hrs.	2210°
BAILEY. Same floor as tested January 5, 1897, with ceiling replaced.	Feb. 13, 1897.	14′	4′	14′	11′	"	10′	2	4	15″x15″	.....	.....	.....	5 hrs.	1880°
GUASTAVINO. Tile dome.	Apr. 2, 1897.	.....	.....	15′	12′	"	10′	2	4	.....	.....	.....	30 days	5 hrs.	2116°
GUASTAVINO. Tile dome. Same floor as tested April 2.	Apr. 15, 1897.	.....	.....	15′	12′	"	10′	2	4	.....	.....	.....	.....	5 hrs.	1883°
MANHATTAN. Cinder concrete slab reinforced with expanded metal.	Apr. 19, 1897.	14′	4′	14′	11′	"	10′	2	4	15″x15″	.....	.....	31 days	5 hrs.	1746°
Expanded metal. Cinder concrete. I beams. Expanded metal cloth.	Apr. 23, 1897.	14′	4′	14′	10′–3″	"	11′–9″	2	4	15″x15″	.....	.....	45 days	5 hrs.	1832°
METROPOLITAN. Plaster and shavings. Reinforced with wire cable. I beams.	May 20, 1897.	14′	4′	14′	11′	"	10′	.....	4	15″x15″	.....	.....	37 days	5 hrs.	1747°
METROPOLITAN. Terra cotta.	May 20, 1897.	.....	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....
KUHNE. Cinder concrete.[1] Trussed metal lath.	Nov. 27, 1901.	.....	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....
RANSOME.	Nov. 30, 1901.	.....	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....
WIGHT-EASTON. Cinder concrete. Metal fabric.	Feb. 4, 1902.	14′	5′	14′	14′	Brick.	9′–6″	1	4	15″x15″	.....	.....	28 days	4 hrs. 30 min.	1719°
AMERICAN. Cinder concrete.	May 2, 1902.	14′	5′–6″	14′	14′	"	10′	1	4	16″x16″	.....	.....	28 days	4 hrs.	1830°
WHITE. Cinder concrete. Reinforce with round bars.	May 8, 1902.	14′	6′–1″	14′	14′	"	10′	.....	...	.....	.....	.....	28 days	4 hrs.	1752°
KROLMAN. Cinder concrete. 2 I beams. T bar reinforcement.	July 7, 1902.	14′	6′–1″	14′	14′	"	9′–6″	1	4	.....	.....	Brick.	31 days	4 hrs.	1745°
AMERICAN CONCRETE STEEL. Cinder concrete.	Sept. 10, 1902.	14′	6′	21′	14′	"	9′–6″	1	6	15″x15″	.....	"	28 days	4 hrs. 13 min.	1715°
Reinforced cement construction.	Mar. 27, 1903.	.....	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....
COLUMBIAN. Cinder concrete. Steel bar reinforcement. 2 I beam.	Apr. 21, 1903.	14′	6′	14′	12′	Brick.	10′	1	4	16″x16″	6′	Brick.	.....	4 hrs.	.....
COLUMBIAN. Slag concrete.	Apr. 21, 1903.	14′	15′	14′	24′	"	10′	1	6	16″x16″	6′	"	.....	.....	1695°
ELKOP.	Apr. 22, 1903.	.....	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....
DE MAN. Cinder concrete.	Apr. 24, 1903.	14′	6′ and 4′	18′	14′	Brick.	.....	1	4	12″x12″	.....	Brick.	28 days	4 hrs. 6 min.	1715°
Reinforced cement construction. Stone concrete.	June 17, 1903.	14′	6′	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....
COLUMBIAN Slag concrete.	July 9, 1903.	14′	15′	24′	14′	Brick.	10′	1	6	16″x16″	6′	Brick.	.....	4 hrs.	1715°
COLUMBIAN. Cinder concrete.	July 9, 1903.	14′	6′	14′	12′	"	10′	1	4	16″x16″	6′	"	.....	4 hrs.	1815°
INTERNATIONAL. Cinder concrete.	July 31, 1903.	14′	6′	18′	14′	"	9′	2	4	.....	.....	.....	30 days	2 hrs. 30 min.	1715°
WAITE. Cinder concrete. Slab and lintels.	Aug. 10, 1903.	14′	3′–6″	14′	14′	Concrete.	9′–6″	3	4	15½″ x15½″	.....	Concrete.	33 days	4 hrs.	1771°
INTERNATIONAL. Cinder concrete. Metal fabric.	Sept. 10, 1903.	14′	6′	18′	14′	Brick.	9′	2	4	.....	.....	Brick.	34 days	4 hrs. 5 min.	1715°
CELLULAR. Dovetailed sheet metal. Slag concrete.	Oct. 10, 1903.	14′	2′–6″	14′	6′–6″	"	9′–6″	1	4	15″x15″	.....	"	2 mos.	.....	1600°
Reinforced cement construction. Stone concrete. 2 reinforced concrete girders. Steel bar reinforcement.	Nov. 17, 1903.	16′–8″	4′–4″	20′	8′	"	9′–6″	1	4	14″x14″	.....	"	58 days	4 hrs. 15 min.	1715°
NATIONAL. Hollow tile flat arch. Reinforced with woven wire. I beams.	Nov. 23, 1903.	.....	6′	14′	12′	"	9′–6″	.....	4	.....	.....	"	.....	4 hrs.	1715°

RE TESTS OF FLOORS.

Fire Test.								Load after Fire.		Results.	Max. Deflection.	Action of Bureau of Buildings New York
a- of e.	Av. Temp. °F.	No. of Couples.	Fuel.	Load. Amt.	Load. Kind.	Water Pressure.	Size Nozzle.	Amount.	Kind.			
				Pounds		Pounds.		Pounds.				
r. in.	1600°	1	Cordwood.	150 per sq. ft.	.....	.....	.....	186 per sq. ft.	.....	Plaster nearly all down. Wire cloth intact. Arch in good condition.	.....	Approved
rs. in.	1988°	1	"	150 per sq. ft.	.....	.....	1½"	600 per sq. ft.	.....	Majority of tile lintels cracked, lower part broken off and concrete washed in places.	5½"	"
rs.	Fusible Plug. Temp. Melting Iron.	.....	"	150 per sq. ft.	Brick.	60	1½"	600 per sq. ft.	Brick.	Plaster washed off. 35 per cent. blocks cracked and lower section off to a depth of 3½".	2⅛"	"
rs.	1740°	1	"	150 per sq. ft.	.....	60	1½"	600 per sq ft.	.....	Plaster off. Part of bricks fallen.	2.37"	"
rs.	1779°	1	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plaster and wire netting off. Concrete arch in good condition.	4.48"	"
rs.	1900°	1	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Concrete washed away in center of arch exposing tie rods.	.....	"
rs.	1950°	1	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Ceiling intact after fire. Water washed off a small portion of floor blocks.	.295"	"
...	.....	.....	"	150 per sq. ft.	.....	.....	.....	600 per sq. ft.	.....	.....	.....	No action.
rs.	1985°	.....	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plaster washed away exposing sheet metal. Floor otherwise in good condition.	3.06"	Approved.
rs.	1825°	.....	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plastering washed away. Concrete washed. Large part of beam protection off.	.....	"
rs.	2210°	.....	"	150 per sq. ft.	.....	60	1½"	.....	.....	Middle arc broken through sleeper and tie rods exposed.	.....	
rs.	1880°	.....	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plaster off. Dovetailed metal exposed and burnt through in places.	2½"	"
rs.	2116°	.....	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Part of tiles fell on application of water. Thin crack in dome.	.665"	"
rs.	1883°	.....	"	150 per sq. ft.	.....	60	1½"	450 per sq. ft.	.....	Two course of tiles fell leaving one course of dome standing.	.18"	"
rs.	1746°	.....	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plaster washed off and concrete washed one inch above expanded metal. Flanges of beams exposed.	1"	"
rs.	1832°	.....	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plaster and concrete washed exposing expanded metal and tie rods. Expanded. Metal cloth off in places.	3.00"	"
rs.	1747°	.....	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Ceiling nearly all down, wire mesh partly gone. Beams exposed in places. Wire cables exposed.	.36"	"
...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	No action.
...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Failure.
...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	No action.
rs. in.	1719°	1	Cordwood.	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plaster all off. Tie rods and metal fabric exposed.	.44"	Approved.
rs.	1830°	1	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plaster destroyed. T bars exposed. Floor otherwise intact.	1.32"	"
rs.	1752°	.....	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plaster destroyed. Two bars exposed. Beam protection in good condition. Floor otherwise in good condition.	1.72"	"
rs.	1747°	1	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plaster all washed off. Parts of lower flanges of both beams exposed. Concrete in good condition.	.113"	"
rs. in.	1713°	.....	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plaster all off. Tees and wires nearly all exposed.	1⅛"	"
...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Failure.
rs.	.....	3	Cordwood.	150 per sq. ft.	Pig iron	60	1½"	600 per sq. ft.	Pig iron	Plaster all off. Flanges of both beams exposed.	⅛"	Approved.
...	1699°	3	"	150 per sq. ft.	"	.....	.....	.....	.....	.....	.....	Failure.
...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	"
rs. in.	1717°	1	Cordwood.	150 per sq. ft.	.....	90	1½"	600 per sq. ft.	.....	About one-third plaster gone. Lower flange of one beam exposed. Concrete slightly washed; otherwise in good shape.	3/16"	Approved.
...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	No action.
rs.	1720°	3	Cordwood.	150 per sq. ft.	Pig.	60	1½"	600 per sq. ft.	Pig.	In good condition.	2 1/16"	Approved.
rs.	1870°	3	"	150 per sq. ft.	"	60	1½"	600 per sq. ft.	"	In good condition.	1/8"	"
rs. in.	1715°	2	"	150 per sq. ft.	.....	60	1½"	None.	.....	Collapsed.	.....	Failure.
rs.	1770°	2	"	150 per sq. ft.	.....	55	1¼"	600 per sq. ft.	.....	Plaster nearly all gone. Concrete slightly washed. Flanges of lintels cracked.	1⅛"	Approved.
rs. in.	1710°	2	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Concrete protecting beams gone. Concrete washed, but no metal fabric exposed.	.....	"
...	1640°	1	"	150 per sq. ft.	.....	.....	.....	.....	.....	Collapsed after 2½ hours.	.....	Failure.
rs. in.	1720°	2	"	150 per sq. ft.	.....	.....	1½"	600 per sq. ft.	.....	Concrete pitted, exposing some reinforcing rods. Rods exposed in girders.	.....	Approved.
rs.	1734°	3	"	150 per sq. ft.	Brick.	.....	.....	600 per sq. ft.	Brick.	Plaster nearly all gone. Tile covering of beams off. Lower part of two tiles gone.	.....	

Cinder concrete. Metal fabric.	10, 1903.	14′	6′	18′	14′	Brick.	9′	2	4	.....	.....	Brick.	34 days	4 hrs. 5 min.	1710
CELLULAR. Dovetailed sheet metal. Slag concrete.	Oct. 10, 1903.	14′	2′–6″	14′	6′–6″	"	9′–6″	1	4	15″x15″	.....	"	2 mos.	.....	1640
Reinforced cement construction. Stone concrete. 2 reinforced concrete girders. Steel bar reinforcement.	Nov. 17, 1903.	16′–8″	4′–4″	20′	8′	"	9′–6″	1	4	14″x14″	.....	"	58 days	4 hrs. 15 min.	1720
NATIONAL. Hollow tile flat arch. Reinforced with woven wire. I beams.	Nov. 23, 1903.	.....	6′	14′	12′	"	9′–6″	.....	4	.....	.....	"	.....	4 hrs.	1730
CLINTON Cinder concrete. Steel wire reinforcement. I beams.	Dec. 21, 1903.	14′–2″	15′	.....	14′–2″	"	.....	1	4	.....	.....	"	40 days	4 hrs. 5 min.	1710
CLINTON. Cinder concrete. Steel wire reinforcement. I beams.	Dec. 21, 1903.	14′–2″	6′	.....	14′–2″	"	.....	1	4	.....	.....	"	40 days	4 hrs.	1780
CELLULAR. Stone concrete. Dovetailed metal centering.	Dec. 29, 1903.	14′	[3′–6″	14′	6′–6″	"	9′–6″	1	4	15″x15″	.....	"	15 days	4 hrs. 5 min.	1710
Expanded metal. Trap concrete. Expanded steel reinforcement.	June 14, 1904.	14′	15′	19′	14′–6″	"	.....	2	6	.....	.....	"	28 days	4 hrs.	1730
EXCELSIOR. Cinder concrete.	July 14, 1904.	14′	6′	14′	12′	"	10′	1	4	16″x16″	.....	"	27 days	4 hrs. 10 min.	1710
HENNEBIQUE. Slag and stone concrete. 2 reinforced concrete girders. Steel bar reinforcement.	July 20, 1904.	9′ and 12′–8″	6′	15′–4″	14′	"	9′–7½″	.....	4	.....	.....	.....	.....	.....	1730
Expanded metal. Cinder concrete. Expanded metal reinforcement. 2 I beams.	Aug. 3, 1904.	14′	15′	20′	14′	"	.....	2	6	.....	.....	Brick.	28 days	4 hrs	1760
SIEGWART. Grit concrete. Hollow beams. Steel rod reinforcement.	Aug. 9, 1904.	16½′	.....	20′	12′	"	8′–6″	1	6	.....	.....	"	48 days	4 hrs.	1700
NATIONAL.	Sept. 23, 1904.	.....	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....
KAHN. Stone concrete. 2 beams reinforced concrete. Steel bar reinforcement.	Sept. 30, 1904.	14′	15′	19′	14′	Brick.	9′–0″	2	6	12″x12″	5′	Brick.	29 days	4 hrs.	1710
OLIVER, C. D. Cinder concrete. 2 I beams. Steel bar reinforcement.	Nov. 1, 1904.	.....	.....	.....	.....	Concrete.	.....	.....	...	.....	.....	Concrete.	.....	1 hr.	.....
TURNER. Stone concrete. 2 beams. Steel bar reinforcement.	Nov. 22, 1904.	16′	6′	19′	14′	Brick.	9′–0″	2	6	12″x12″	5′	Brick.	.....	3½ hrs.	16
UNIT. Trap concrete. 2 reinforced concrete beams. Steel bar reinforcement.	Dec. 21, 1904.	18′	8′	19′–6″	10′–6″	"	9′–6″	2	4	18″x18″	7′–6″	"	.....	3½ hrs.	17
NATIONAL. Terra cotta. 2 I beams. Woven wire reinforcement.	Mch. 27. 1905.	14′	7′–6″	14′	13′	"	9′–6″	1	4	.....	.....	"	33 days	4 hrs.	17
TURNER. Trap concrete. 2 reinforced concrete beams. Steel bar reinforcement.	May 1, 1905.	16′	6′	18′	13′	Concrete.	10′	2	4	18″x18″	5′	Concrete.	7 weeks	4 hrs.	17
MENCZARSKI. Cinder concrete. 4 I beams. Flat bar reinforcement.	May 3, 1905.	14′	4′ 5′ and 6′	19′	14′	Brick.	9′	2	6	12″x12″	5′	Brick.	30 days	4 hrs.	1
CEMENTAL. Cinder concrete. 4 I beams. Steel bar reinforcement.	May 8, 1905.	13′–8″	7′–6″	20′	13′–8″	"	9′–6″	2	4	16″x16″	.....	"	28 days	4 hrs.	1
UNIT. Trap concrete. 2 reinforced concrete beams. Steel bar reinforcement.	June 16. 1905.	19½′	4′	20′–2″	10′–6″	"	9′–8″	2	4	18″x18″	7′–6″	"	60 days	4 hrs.	1
ST. LOUIS EXPANDED METAL. Stone concrete. 3 reinforced beams. Steel bar reinforcement.	July 13, 1905.	14′	5′	19′	14′	"	9′	2	6	12″x12″	5′	"	34 days	4 hrs.	1
PIERCE. Cinder concrete.	Sept. 19. 1905.	14′	7′–0″ and 6′–0″	18′	14′	"	9′	2	4	.....	.....	.....	39 days	4 hrs.	1
WAITE. Stone concrete 2 reinforced girders. Steel bar reinforcement.	Nov. 11, 1905.	14′	6′	14′	13′–4″	Concrete.	9′–6″	1	4	18″x18″	5′	Concrete.	2 mos.	4 hrs.	1
WAITE. Cinder concrete. 2 reinforced girders. Steel bar reinforcements.	Nov. 11, 1905.	14′	4′–4″	14′	11′–8″	"	9′–6″	1	4	18″x18″	5′	"	2 mos.	4 hrs.	1
ST. LOUIS EXPANDED METAL. Stone concrete. Reinforced with Johnson bars.	Dec. 26, 1905.	14′ and 12′–6″	5′	14′	11′	"	9′–6″	1	4	12″x16″	.....	.....	48 days	4 hrs.	1
ST. LOUIS EXPANDED METAL. Cinder concrete.	Dec. 26, 1905.	14′	8′	14′	11′	"	9′–6″	1	4	12″x16″	.....	.....	47 days	4 hrs.	1

hrs. min.	1710°	2	"	per sq. ft.	.....	60	1½"	per sq. ft.	.....	Concrete washed, but no metal fabric exposed.	.....	"
.....	1640°	1	"	150 per sq. ft.	.....	.....	.....	.....	.....	Collapsed after 2½ hours.	.....	Failure.
hrs. min.	1720°	2	"	150 per sq. ft.	.....	.....	1½"	600 per sq. ft.	.....	Concrete pitted, exposing some reinforcing rods. Rods exposed in girders.	.....	Approved.
hrs.	1734°	3	"	150 per sq. ft.	Brick.	.....	.....	600 per sq. ft.	Brick.	Plaster nearly all gone. Tile covering of beams off. Lower part of two tiles gone.	.....	"
hrs. min.	1714°	2	"	150 per sq. ft.	Pig.	60	1½"	600 per sq. ft.	Pig.	Plaster entirely gone. Concrete somewhat washed.	3½"	"
hrs.	1783°	2	"	150 per sq. ft.	"	60	1½"	600 per sq. ft.	"	Plaster all gone, and concrete washed away to reinforcing wires in some places. Otherwise in good condition.	¼"	
hrs. min.	1710°	2	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Plaster all off, exposing metal. Floor cracked along beams.	1 9/16"	"
hrs.	1739°	5	"	150 per sq. ft.	Pig.	60	1½"	600 per sq. ft.	Pig.	Large crack in ceiling. Expanded metal hanging. Test stopped.	5 3/16"	Failure.
hrs. min.	1710°	2	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	"	Plaster washed away. Cinder concrete unharmed.	1/16"	Approved.
.....	1732°	2	"	150 per sq. ft.	Pig.	60	1½"	600 per sq. ft.	Pig.	Plaster all off. Surface of slabs pitted. Bars exposed in girders.	.....	"
hrs	1767°	5	Cordwood.	150 per sq. ft.	Pig.	60	1½"	600 per sq. ft.	Pig.	A large part of the expanded metal exposed. Metal lath on beams exposed.	1 1/16"	Approved.
hrs.	1798°	3	Cordwood.	150 per sq. ft.	Pig.	60	1½"	600 per sq. ft.	Pig.	Plaster off. Metal lathing hanging in places. Beams in good condition.	.....	"
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
hrs	1728°	3	Cordwood.	150 per sq. ft.	Pig.	60	1½"	600 per sq. ft.	Pig.	Ceiling in good condition. Several cracks in floor. Very little metal exposed.	4 3/16"	Approved.
hr.	.....	3	"	150 per sq. ft.	Pig.	60	1½"	.....	.....	Floor fell on application of water.	.....	Failure.
½ hrs.	1673°	3	"	150 per sq. ft.	Pig.	60	1½"	.....	.....	Partly failed. Test stopped.	.....	"
½ hrs.	1708°	3	"	150 per sq. ft.	Pig.	.....	.....	.....	.....	Floor fell at 3.30.	.....	"
4 hrs.	1711°	2	"	150 per sq. ft.	Pig.	60	1½"	600 per sq. ft.	Pig.	Plaster all off. Several small cracks in floor. Bottom webs of several tiles gone.	3 3/16"	Approved.
4 hrs.	1706°	3	"	150 per sq. ft.	Sand.	60	1½"	600 per sq. ft.	Sand.	Rods exposed in one girder by water. Floor slabs slightly pitted. Otherwise in good condition.	¼"	"
4 hrs.	1707°	3	"	150 per sq. ft.	Pig.	60	1½"	600 per sq. ft.	Pig.	All spans in good condition. Slightly washed. Few small cracks.	1/16" 1/32" 1/16"	"
4 hrs.	1707°	3	"	150 per sq. ft.	Billets.	60	1½"	600 per sq. ft.	Billets.	Concrete pitted. Metal exposed on one beam.	1/32" 1/32"	"
4 hrs.	1708°	3	"	150 per sq. ft.	Pig.	60	1½"	650 per sq. ft.	Pig.	Floor slabs in good condition. Metal badly exposed on beams.	2"	"
4 hrs.	1703°	3	"	150 per sq. ft.	Pig.	60	1½"	350 per sq. ft.	Pig.	Concrete washed from beams, exposing reinforcing bars. Metal exposed in floor slabs.	5 1/16"	Failure.
4 hrs.	1700°	2	"	150 per sq. ft.	.....	60	1½"	610 per sq. ft.	.....	6-ft. span collapsed, due to bad construction of test house. 7-ft. span: concrete washed away, exposing 3 reinforcing bars.	— 4½"	— Approved.
4 hrs.	1700°	2	"	150 per sq. ft.	Sand.	60	1½"	600 per sq. ft.	Sand.	Small cracks along girders. Reinforcing rods partly exposed. Floor slabs in fair condition.	2½"	
4 hrs.	1710°	2	"	150 per sq. ft.	Sand.	60	1½"	600 per sq. ft.	Sand.	Girders badly washed. Floor slabs pitted, but no metal exposed.	1½"	
4 hrs.	1702°	.....	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Rods of beams exposed by water. Otherwise in good condition.	3 1/16"	
4 hrs.	1656°	.....	"	150 per sq. ft.	.....	60	1½"	600 per sq. ft.	.....	Rods of slabs exposed at center of bays by water. Girder protection intact.	6½"	

TABLE I.—FIRE TESTS MADE BY THE BRITISH FIRE P

Kind of Floor	Date of Test.	Floor Construction.			Test Structure.							Age.	D t
		Span Beam.	Span Slab.	Area Sq. Ft.	Length.	Width.	Walls. Thickness.	Walls. Material.	Height Floor.	Firing Doors.	Draught Holes.		
3 steel joists and coke breeze concrete.	Oct. 18, 1899.	10′	2′-6″	100	10′	10′	12″	Stock brick, lime and mortar.	8′	None.	24	6 wks.	1 37
4 parallel steel joists, filled in with concrete on corrugated iron; with a suspended ceiling.	May 25, 1899.	10′	3′	100	10′	10′	12″	"	7′-6″	.....	24	1 mo.	1 15
Concrete floor supported by 3 steel I beams and expanded metal with suspended expanded metal ceiling.	Feb. 15, 1899.	10′	4′-9½″	100	10′	10′	12″	"	7′-6″	.....	24	3 mos.	1 15
Concrete floor laid on 4 I beams and terra cotta wired lathing, with suspended ceiling of the latter.	Jan. 11, 1899.	10′	3′-3″	100	10′	10′	12″	"	7′-5″	.....	24	6 wks.	1 15
Same as above. Ceiling replastered.	July 25, 1900.	10′	3′-3″	100	10′	10′	12″	"	7′-5″	.....	24	10 days	
Reinforced concrete floor with 2 steel joists.	July 14, 1899.	10′	6′-0″	100	10′	10′	12″	"	8′-0″	.....	24	2 mos.	2
Concrete floor reinforced by 2 I beams, with a suspended ceiling of metal lathing.	May 22, 1901.	22′-3″	3′-4″	222	22′-3″	10′	.....	"	7′-11″	.....	48	2 mos.	
Cement concrete floor, made in 7 bays with various mixture of concrete: 3 blast furnace slag, 2 clean sand, 1 cement.	Oct. 25, 1905.	10′-2″	2′-7″	.....	22′-4″	10′-2″	.....	"	8′-3″	.....	22	40 days	
3 broken brick, 2 clean sand, 1 cement.	.....	.....	.....	.....	.....	.....	.....	"	.....	.....	.....	.....	
3 broken granite, 2 clean sand, 1 cement.	.....	.....	.....	.....	.....	.....	.....	"	.....	.....	.....	.....	
5 burnt ballast, 1 cement.	.....	.....	.....	.....	.....	.....	.....	"	.....	.....	.....	.....	
5 coke breeze, 1 cement.	.....	.....	.....	.....	.....	.....	.....	"	.....	.....	.....	.....	
3 furnace cinder, 2 clean sand, 1 cement.	.....	.....	.....	.....	.....	.....	.....	"	.....	.....	.....	.....	
3 Thames ballast, 2 clean sand, 1 cement.	.....	.....	.....	.....	.....	.....	.....	"	.....	.....	.....	.....	
2 steel I beams and coke breeze concrete.	May 10, 1901.	10′	3′-4″	77	10′	7′-8″	12″	"	9′-6″	.....	30	6 wks.	
2 broad flanged beams and Thames ballast concrete, reinforced by light steel joists.	Aug. 17, 1905.	15′	7′	334	22′-3″	15′	.....	"	8′-1″	.....	.....	70 days	
2 broad flanged beams and clinker and coke breeze concrete, reinforced by light steel joists.	Feb. 24, 1906.	15′	7′-0″	334	22′-3″	15′	.....	"	8′-1″	.....	.....	65 days	

FIRE PREVENTION COMMITTEE ON CONCRETE FLOORS.

Fire Test.												Results.	Deflections.		
Age.	Duration Fire.	Temp. ° F.	Pyrometers. No.	Pyrometers. Location.	Fuel.	Load during Test. Am't.	Load during Test. Kind.	Load during Test. Area.	Water Pressure.	Size Nozzle.	Time of Application.		Beginning of Fire.	At End of Fire.	After Water
6 wks.	1 hr. 37 min.	1130 1650	4	Through walls beneath floor.	Gas.	Pounds 168 per sq. ft.	Bricks.	9′x9′	Pounds 20	¾″	2 min.	Two outer bays collapsed, so test was stopped. Badly deflected.	R+1¼″ M+1″ L+1″	10.5″ 6.25″ 7.	12.″ 11.75″ 12.25″
1 mo.	1 hr. 15 min.	170 2010	5	"	"	168 per sq. ft.	"	9′x9′	20	¾″	3 min.	Suspended ceiling fell down. Fire did not go through floor.	I+¼″ II+¼″	2¼″ 2¼″	.....
3 mos.	1 hr. 15 min.	300 2400	5	"	"	140 per sq. ft.	Pig iron	9′x9′	40 to 20	¾″	3 min.	Suspended ceiling fell. Floor slightly disintegrated on lower side.	.....	.....	L 0 M 1⅛″ R ⅞″
6 wks.	1 hr. 15 min.	600 2000	5	"	"	150 per sq. ft.	Bricks.	9′x9′	25	¾″	2 min.	Plaster off suspended ceiling. Floor uninjured.	.....	.....	.....
10 days	1 hr.	400 1950	5	"	"	150 per sq. ft.	"	9′x9′	25	¾″	2 min.	Plaster off suspended ceiling. Floor uninjured.	.....	.....	.....
2 mos.	2½ hrs.	500 2300	5	"	"	168 per sq. ft.	"	9′x9′	25 to 30	¾″	3 min.	Two-thirds plaster off. [Floor uninjured.	.....	.....	.....
2 mos.	3 hrs.	500 1700	9	"	"	200 per sq. ft.	"	7′7″x8′	20	¾″	2 min.	Few cracks; floor otherwise in in good shape.	.....	.....	1″
40 days	3 hrs.	900 1900	9	"	"	224 per sq. ft.	"	.....	65	¾″	3 min.	Practically flat underneath; cracked across top in two places.	.....	.....	.....
.....	.....	.....	...	.....	.....	.....	.....	.....	.....	.....	.....	Curved downward. Cracked across top in three places.	.....	.....	.....
.....	.....	.....	...	.....	.....	.....	.....	.....	.....	.....	.....	Curved downward about ¼″. About 1″ washed off surface in one part, and more or less all over. Three cracks on top.	.....	.....	.....
.....	.....	.....	...	.....	.....	.....	.....	.....	.....	.....	.....	Curved downward about ¼″ on bottom. About 3″ washed off surface in one part, and more or less all over.	.....	.....	.....
.....	.....	.....	...	.....	.....	.....	.....	.....	.....	.....	.....	Flat underneath. About 1″ washed off surface. No cracks on top. Top not curved.	.....	.....	.....
.....	.....	.....	...	.....	.....	.....	.....	.....	.....	.....	.....	Flat underneath.	.....	.....	.....
.....	.....	.....	...	.....	.....	.....	.....	.....	.....	.....	.....	Curved downward about 1¼″. Several bad cracks. Surface very badly damaged all over.	.....	.....	.....
6 wks.	2½ hrs.	500	5	Through walls beneath floor.	Gas.	None.	.....	.....	15 to 20	¾″	2 min.	Concrete disintegrated for about three-fourths of an inch. Otherwise sound.	.....	.....	.....
70 days	4 hrs.	760 1700	5	"	"	280 per sq. ft.	Bricks.	.....	.....	¾″	5 min.	About one-third of floor fell. Lower flanges of beams exposed. Floor badly damaged.	.....	.....	.....
65 days	4 hrs.	900 1900	5	"	"	280 per sq. ft.	"	.....	.....	¾″	5 min.	Few small cracks. Floor otherwise in good shape.	.....	.....	.....

REPORT OF COMMITTEE Q ON STANDARD SPECIFICATIONS FOR THE GRADING OF STRUCTURAL TIMBER.

The following is submitted as a progress report of Committee Q on the Standard Specifications for Grading of Structural Timber:

In view of the large scope of the work entrusted to this Committee it was agreed that the Committee confine its work for the present year to a collection and illustration of standard defects occurring in structural timber, with particular reference to yellow pine and Douglas fir, with a description of these defects, and a study of the present knowledge concerning influence which these defects have on the strength of timber. The work of the Committee has furthermore been directed towards the consideration of what shall be considered *structural timbers*. The following is submitted as a progress report for the purpose of discussion:

I.

Definition of Structural Timber.

By the term "Structural Timber" the Committee understands all such products of wood in which the strength of the timber is the controlling element in their selection and use. The following is a list of products which are recommended for consideration as structural timbers:

Trestle Timbers.—Stringers, caps, posts, mud sills, bracing, bridge ties, guard rails.

Car Timbers.—Car framing, including upper framing; car sills.

Framing for Buildings.—Posts, mud sills, girders, framing, joists.

Ship Timbers.—Ship timbers, ship decking.

Cross Arms for Poles.

It was recommended to omit for the present the following products: Railway ties, poles, piling, car flooring, mine props.

Acknowledgment is made to the *Engineering Record* for the cuts used in this paper.—Ed.

The following products were not considered to come within the work of the committee: Vehicle woods, tank stock, packing box material.

II.

STANDARD DEFECTS.

The standard defects included in the following list are mostly such as may be termed natural defects, as distinguished from defects of manufacture. The latter have usually been omitted, because the defects of manufacture are of very minor significance in the grading of structural timber:

1. *Sound Knot.*—A sound knot is one which is solid across its face and which is as hard as the wood surrounding it; it may be either red or black, and is so fixed by growth or position that it will retain its place in the piece.

2. *Loose Knot.*—A loose knot is one not firmly held in place by growth or position.

3. *Pith Knot.*—A pith knot is a sound knot with a pith hole not more than $\frac{1}{4}$ inch in diameter* in the center.

4. *Encased Knot.*—An encased knot is one which is surrounded wholly or in part by bark or pitch. Where the encasement is less than $\frac{1}{8}$ of an inch in width on both sides, not exceeding one-half the circumference of the knot, it shall be considered a sound knot.

5. *Rotten Knot.*—A rotten knot is one not as hard as the wood it is in.

6. *Pin Knot.*—A pin knot is a sound knot not over $\frac{1}{2}$ inch in diameter.

7. *Standard Knot.*—A standard knot is a sound knot not over $1\frac{1}{2}$ inches in diameter.

8. *Large Knot.* A large knot is a sound knot, more than $1\frac{1}{2}$ inches in diameter.

9. *Round Knot.*—A round knot is one which is oval or circular in form,

10. *Spike Knot.*—A spike knot is one sawn in a lengthwise direction; the mean or average diameter shall be considered in measuring these knots.

* Measurements which refer to the diameter of knots or holes should be considered as referring to the mean or average diameter.

11. *Pitch Pockets.*—Pitch pockets are openings between the grain of the wood containing more or less pitch or bark. These shall be classified as *small, standard* and *large* pitch pockets.

(*a*) *Small Pitch Pocket.* A small pitch pocket is one not over $\frac{1}{8}$ of an inch wide.

(*b*) *Standard Pitch Pocket.* A standard pitch pocket is one not over $\frac{3}{8}$ of an inch wide, or 3 inches in length.

(*c*) *Large Pitch Pocket.* A large pitch pocket is one over $\frac{3}{8}$ of an inch wide, or over 3 inches in length.

12. *Pitch Streak.*—A pitch streak is a well-defined accumulation of pitch at one point in the piece. When not sufficient to develop a well-defined streak, or where the fiber between grains, that is, the coarse-grained fiber, usually termed "Spring wood," is not saturated with pitch, it shall not be considered a defect.

13. *Wane.*—Wane is bark, or the lack of wood from any cause, on edges of timbers.

14. *Shakes.*—Shakes are splits or checks in timbers which usually cause a separation of the wood between annual rings.

15. *Rot, Dote* and *Red Heart.*—Any form of decay which may be evident either as a dark red discoloration not found in the sound wood, or the presence of white or red rotten spots, shall be considered as a defect.

III.

STANDARD NAMES FOR STRUCTURAL TIMBERS.

As indicated in the report of the Committee for 1905, one of the most important matters for consideration will be the adoption of a series of common names which shall be regarded as standard for structural timbers. The rapid introduction into the Eastern States of Pacific coast woods with names similar to those hitherto used by architects and engineers from eastern sources has brought about much confusion. In considering this subject the Committee has endeavored to select names which shall be as nearly as possible in accordance with the trade names most universally employed. Attention is called to the fact, however, that it has been the object of the Committee to give dis-

tinctive names to woods which have distinctive characteristics. The term "White Pine" may be taken as an example. White pine as ordinarily used in the lumber markets, up to within a few years, meant a soft white pine which for half a century or more came from Maine, Michigan, Wisconsin and Minnesota. White pine, to the majority of manufacturers and users, of the Mississippi valley and eastward, still means this timber. Of late years a form of pine has come from Idaho, which is sold under the name "White Pine;" and another kind of timber has come from California which is likewise sold as white pine. The three timbers are distinct forms of wood, and the same name given to all three has given rise to much confusion. The following list is presented as a preliminary one by the Committee. In it are included such timbers as are believed to be structural timbers:

1. *Southern Yellow Pine.*—Under this heading two classes of timber are used, (*a*) Longleaf Pine, (*b*) Shortleaf Pine.

It is understood that these two terms are descriptive of quality, rather than of botanical species. Thus, shortleaf pine would cover such species as are now known as North Carolina pine, loblolly pine, and shortleaf pine. "Longleaf Pine" is descriptive of quality, and if shortleaf or loblolly pine is grown under such conditions that it produces a large percentage of hard summer wood, so as to be equivalent to the wood produced by the true longleaf, it would be covered by the term "Longleaf Pine."

2. *Douglas Fir.*—The term "Douglas Fir" to cover the timber known likewise as yellow fir, red fir, western fir, Washington fir, Oregon or Puget Sound fir, norwest and west coast fir.

3. *Norway Pine,* to cover what is known also as "Red Pine."

4. *Hemlock,* to cover Southern or Eastern hemlock; that is, hemlock from all States east of and including Minnesota.

5. *Western Hemlock,* to cover hemlock from the Pacific coast.

6. *Spruce,* to cover Eastern spruce; that is, the spruce timber coming from points east of Minnesota.

7. *Western Spruce,* to cover the spruce timber from the Pacific coast.

FIG. 1.—Loose Knot.

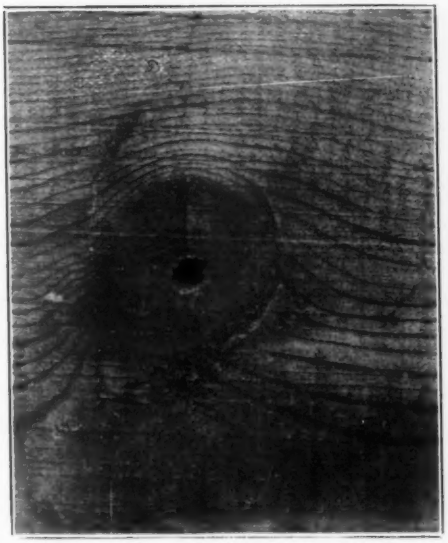


FIG. 2.—Pith Knot.

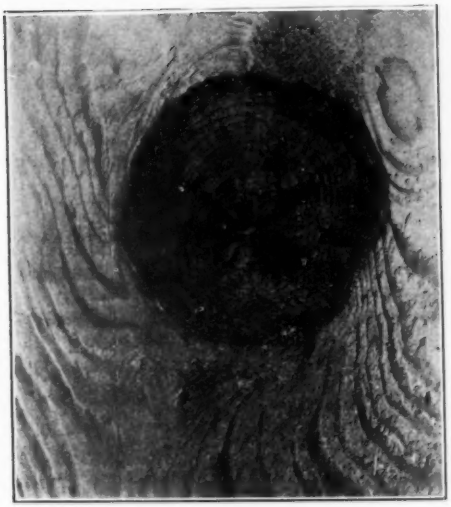


FIG. 3.—Encased Knot.

FIG. 4.—Rotten Knot.

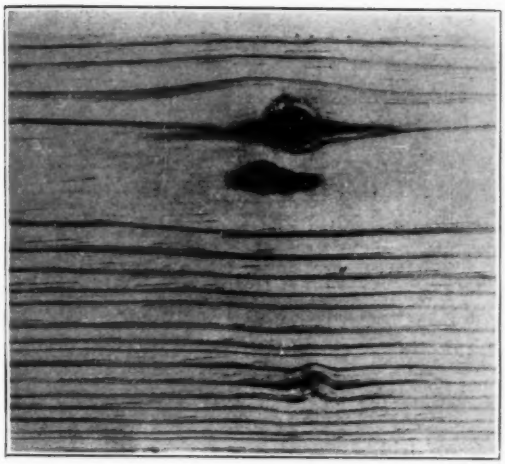


FIG. 5.—Pin Knot.

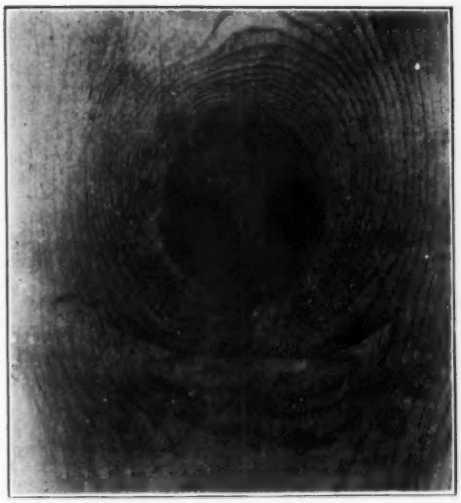


FIG. 6.—Standard Knot.

FIG. 7.—Large Knot.

FIG. 8.—Spike Knot.

FIG. 9.—Pitch Pocket.

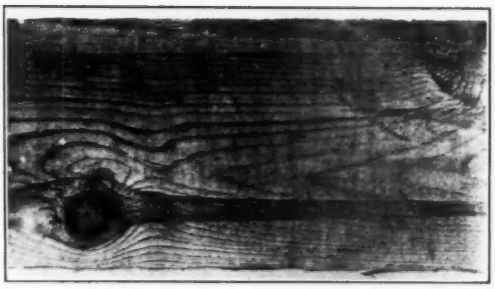


FIG. 10.—Pitch Streak.

8. *White Pine*, to cover the timber which has hitherto been known as white pine, from Maine, Michigan, Wisconsin and Minnesota.

9. *Idaho White Pine*, the variety of white pine from western Montana, northern Idaho, and eastern Washington.

10. *Western White Pine*, to cover the timber sold as white pine coming from Arizona, California, New Mexico, Colorado, Oregon and Washington. This is the timber sometimes known as "Western Yellow Pine," or "Ponderosa Pine," or "California White Pine."

11. *Western Larch*, to cover the species of larch or tamarack from the Rocky Mountain and Pacific coast regions.

12. *Tamarack*, to cover the timber known as "Tamarack," or "Eastern Tamarack," from States east of and including Minnesota.

13. *Redwood*, to include the California wood usually known by that name.

Respectfully submitted on behalf of the committee,

HERMANN VON SCHRENK,
Chairman

W. K. HATT,
Secretary.

DISCUSSION.

Mr. Kellogg. MR. R. S. KELLOGG.—I might say a word in addition. The standard defects listed are word for word the standard defects now in force in the grading rules of the Yellow Pine Manufacturers' Association, headquarters, St. Louis, a large association, which manufactures both short-leaf and long-leaf pine. It seems to me that this list of defects can be enlarged a little. The Georgia Interstate Saw-mill Association, which is a very influential association, in addition to the defects recognized by the Yellow Pine Manufacturers' Association, also recognizes hollow knots and knot holes, which are important defects. The definition of shakes, as given in the progress report, covers only round shakes, and not through shakes. A through shake is a split or check which extends from side to side, edge to edge, or side to edge of the timber. Shakes and splits of that character, it seems to me, should also be recognized.

In reference to the nomenclature of the species mentioned, while I like the term "Norway Pine," it may be somewhat difficult to use it practically, since the white and the Norway pine of the Lake States are very largely graded and sold without distinction under the name "Northern pine." I would suggest that the names applied to the two species of hemlock be Eastern hemlock and Western hemlock. I very much prefer to call *Pinus ponderosa* Western pine instead of Western white pine. This species, of course, is botanically very distinct from the true white pines, and I do not think the Society in this instance should aid the attempt of the trade to put it on the market under a name which does not rightfully belong to it. We also have ample justification for the other term, "Western Pine," since that is the one under which it is marketed by the Association which most largely handles it, that is, the Western Pine Manufacturers' Association, with headquarters at Spokane, Wash.

Mr. Quimby. MR. H. H. QUIMBY.—Mr. Chairman, is it intended that the standard specifications shall prescribe the grades or say what the merchantable grade is, and define it in terms of defects?

MR. KELLOGG.—It would be a very desirable thing, and it seems to me it will be possible for this Committee to do so if it cooperates with the manufacturers. Before we can determine accurately what our grades shall be, we shall have to have a great many mechanical tests of timber. We need sufficient laboratory tests upon commercial timbers to give reliable data upon the influence of various classes of defects, the rate of growth, the portion of the tree used, and other factors. Mr. Kellogg.

MR. QUIMBY.—It seems to me that no tests would be required, simply an agreement, just as we have an agreement on standard specifications of steel for certain purposes, which the manufacturers and consumers can take and agree on grades, specifying what prime grade and merchantable grade is; so that any one reading the specifications for a structure can refer to the grade that he wants to use, and then there is a definition of the grade. It only requires an agreement as to what the grades shall cover. The Committee is not serving its proper function unless it does finally come to the adoption of such standards, and it ought to be practicable to do something like that. We have in some cases now eight different grades of large-size timbers recognized by one association; and the same classes of timber, perhaps, in another association will be thrown into only two or three grades; and it might, perhaps, be arranged to get, say, two or three grades that all the associations will agree to use. Mr. Quimby.

REPORT OF COMMITTEE R ON UNIFORM SPECIFICATIONS FOR BOILERS.

A year ago I had the honor to report to you on progress made, or rather on work done, in the matter of a thorough revision of the regulations of the steamboat inspection service so far as they refer to boilers and boiler material. The importance of a scientifically correct and thoroughly practical law governing these matters in the steamboat inspection service, goes far beyond its legal limitations to vessels plying on the navigable waters of the United States. For it is a matter of experience that cities and counties whose inhabitants are largely interested in this water transport, naturally adopt as their own, ordinances and regulations which have been found of value in marine practice. If, therefore, the steamboat inspection law is properly drawn and founded on the best present practice as to materials and methods of construction, it obtains in this manner the same force and general application as it would have if constitutional limitations did not prevent its statutory application to land boilers, as well as to those on the navigable waters of the United States. For this reason the American Boiler Manufacturers' Association has been actively agitating the matter with the hearty co-operation of the Association of American Steel Manufacturers, on specifications for boiler steel.

On July 11, 1905, I addressed the Secretary of the Association of American Steel Manufacturers, suggesting that an agreement might be reached by the adoption of their specifications as to tensile strength, elongation and elastic limit, by the American Boiler Manufacturers' Association and that they should in turn agree to the American Boiler Manufacturers' Association's specifications of 1889 as to sulphur and phosphorus. The later specifications of the American Boiler Manufacturers' Association in regard to these metalloids were strenuously objected to by the Association of American Steel Manufacturers as being too severe. On July 19, 1905, Mr. A. L. Colby, Secretary of the Association of American Steel Manufacturers, replied that they could not agree to lower their sulphur limit from the present maximum of

.040 per cent.; I reported this state of affairs to the convention of the American Boiler Manufacturers' Association at Toronto on July 25, 1905, and several members of the Association of American Steel Manufacturers being present, by invitation, the question was very thoroughly debated, but without leading to an agreement.

After considerable correspondence on this subject with the officials of the Association of American Steel Manufacturers a joint meeting of the two committees, representing the two associations, was arranged for December 15, 1905, and after a very interesting discussion a memorandum of agreement was drawn up as follows:

Memorandum of Agreement between Committee from Association of American Steel Manufacturers and Committee from American Boiler Manufacturers' Association regarding Steel Specifications.

	Tensile Strength. Pounds.
Flange or boiler steel	55,000 to 65,000
"When it is stipulated that the plates are to be flanged, the physical properties shall be the same as required for fire box steel."	
Fire box steel	52,000 to 62,000
Extra soft steel	45,000 " 55,000

	Elongation in 8 inches. Per cent.
Flange or boiler steel	25
Fire box steel	26
Extra soft steel	28

Elastic limit to be one-half of the ultimate tensile strength.

	Chemical Requirements. Sulphur. Per cent.	Phosphorus. Per cent.
Flange or boiler steel	.04	.06 for acid. .04 for basic.
Fire box steel	.035	.035
Extra soft steel	.035	.035

We, the undersigned members of the Committee, are satisfied that this is a fair, safe and perfectly satisfactory agreement, and wipes out all differences between the American Boiler Manufacturers' Association and

the Association of American Steel Manufacturers. We recommend its adoption to the Association, to take effect as soon as notified that the Association of American Steel Manufacturers has agreed to this action of their committee.

This agreement was referred to the full Committee on "Uniform Boiler Specifications" of the American Boiler Manufacturers' Association and unanimously agreed to, and published to the membership of that association in a circular dated December 22, 1905.

The difference between the American Boiler Manufacturers' Association specifications of 1898 and those of the Association of American Steel Manufacturers of 1903 are mainly on the percentage of phosphorus and sulphur, the former fixing sulphur at .025 per cent. and phosphorus at .03 per cent. for fire box plates, and both at .035 per cent. for shell plates; while latter's specifications fix both at .04 per cent. for fire box steel, and sulphur at .04 per cent. and phosphorus at .06 per cent. for flange or boiler steel.

In the course of the argument I presented results of 599 tests made during the preceding year on boiler plate for the Heine Safety Boiler Company, in which the highest phosphorus was .031 per cent., the lowest .007 per cent. and the average .016 per cent., while the sulphur ran from .036 per cent. down to .013 per cent. with an average of .024 per cent.

Under these circumstances I could not agree that the American Boiler Manufacturers' Association specifications were unnecessarily severe. But to harmonize conflicting opinions the members of the committee of that association expressed themselves as willing to raise the chemical requirements to those mentioned in the memorandum above quoted.

On April 9, 1906, the Association of American Steel Manufacturers met at Pittsburg, and passed the following resolutions:

Resolved, That the Association of American Steel Manufacturers agrees with the Specifications of the American Boiler Manufacturers' Association as modified at the joint meeting of a committee of The Association of American Steel Manufacturers and the American Boiler Manufacturers' Association in New York on December 15, 1905, and as submitted to the Association of American Steel Manufacturers by Colonel E. D. Meier on January 18, 1906, but it is also

Resolved, That the Association of American Steel Manufacturers deems it desirable to still maintain the Standard Specifications of the Association of American Steel Manufacturers as revised February 6, 1903, as the basis for the general trade.

This, then, fixes a substantial agreement on the subject between these two associations.

Knowing the great difficulty to bring conflicting interests together on this question, and believing that any reasonable agreement is preferable to the insistance by each interest on its own preferences, I respectfully suggest a concurrence by our Society in this compromise.

I visited Washington in December, 1905, to urge upon the Department of Commerce and Labor the necessity of creating a commission to thoroughly discuss and revise the existing steamboat inspection law. I found that after a careful study of the subject, the Department had concluded that the appointment of such an expert commission on the general lines as first suggested by the American Boiler Manufacturers' Association in 1902, was the best practical solution of this matter, and had introduced a bill differing only in details from that originally proposed by the American Boiler Manufacturers' Association. I fear, however, that there is no possibility of passing this bill at the present session of Congress, since the rate bill and various pure food bills are engrossing the attention of our legislators to such an extent that this matter is allowed to slumber in committee. We must content ourselves, for the present, with the knowledge that the ventilation which this matter has received from this and other societies, has forced it upon the attention of the executive branch of our government, and that there is reason to hope that in due time the legislative branch may take it up in earnest.

A meeting was held on February 1, 1906, by a committee from the Association of American Steel Manufacturers, at which I was present by invitation, as representing the American Boiler Manufacturers' Association. We met the Board of Supervising Inspectors by appointment, and the subject of boiler materials was thoroughly discussed before them, and the statements made by the steel plate men received most considerate and intelligent attention. Several points in the regulations which created undue hardships for plate manufacturers as well as boiler manufacturers,

were in consequence modified by the Board of Supervising Inspectors.

This hearing convinced me that this Board is giving these matters more careful consideration and study than ever before, and I believe that their hearty co-operation in a general and sweeping improvement in the present steamboat inspection law can be obtained. Their duties and labors fit them especially for a critical examination of any such proposed legislation, and they should certainly be drawn into the discussion when this board of revision is finally created.

Very respectfully submitted,

E. D. MEIER,
Chairman.

REPORT OF COMMITTEE S ON WATERPROOFING.

This report, which can only be one showing progress and attempted formulation of possible methods of procedure is presented merely as information. Committee S was not organized until October 27, 1905, when its first meeting was held. At that time it was determined to institute two sub-committees, A and B; the former to have charge of all matters pertaining to that class of materials added to cement when mixed into concrete or used neat for the purpose of imparting thereto a waterproof condition, the latter to have charge of all other materials of a bituminous or kindred character, superficially applied directly or through any medium to the surface or structures for the purpose of waterproofing same. Chairmen of these sub-committees were appointed and instructions given to attempt tentatively the formulation of program and method of testing to determine primarily the durability of each class of material.

Subsequent to organization, two fairly well attended meetings of the whole Committee were held at intervals of about two months. At the second meeting in New York on February 28, 1906, one day was devoted to the examination of waterproofing methods of several different kinds on actual construction work. Also it was determined through the technical press and by circular letter to attempt to get all possible information as well as samples from every manufacturer of waterproofing material of either class. Unfortunately, though the object and views of the Committee were prominently advertised by the technical papers and a large number of circular letters sent directly to manufacturers, comparatively no response was obtained, and it seems that the Committee will be obliged to purchase samples in the open market.

At the last meeting of the Committee, May 29, reports were presented from the chairmen of the sub-committees and some demonstrations of preliminary investigations made in their laboratories leading up to possible conclusions, from which might be deduced methods of test, but it was the consensus of opinion, that

in the matter of the most desirable test, one showing the durability of material under some accelerated method as against the test of time or service, no satisfactory conclusions as yet could be deduced. This matter is receiving the earnest attention of the Committee, and it is hoped that every member of the Society, vitally and directly interested in the subject of waterproofing, will at once put themselves in communication with the Committee through its chairman or secretary, with suggestions of any kind, no matter how apparently trivial, with the view that out of many councils, light may be thrown upon a subject which is the most important before this Committee, the formulation of an accelerated test method for waterproofing materials or processes.

Respectfully submitted on behalf of the Committee,

W. A. AIKEN,
Chairman.

A. W. DOW,
Secretary.

REPORT OF COMMITTEE T ON THE TEMPERING AND TESTING OF STEEL SPRINGS AND STANDARD SPECIFICATIONS FOR SPRING STEEL.

On account of the delay in getting material for the work on tempering, only a report of progress can be offered at this time. The work will be handled under three sub-committees, one on manufacture of the bar to determine proper material and limit of size, one on tempering, and the third on design.

The particular reason for a standard specification for springs is the difference in height of an elliptic spring under an applied and released load. I submit curve of three semi-elliptic driving springs, the ordinates being applied load and the abscisae, the resulting deflection. These springs are of 13,090 pounds, 12,600 pounds, and 16,150 pounds working load with calculated fiber stress of 80,000 pounds. This is indicated by horizontal dotted line. The specified height is indicated by the vertical dotted line. The first spring was tested to 20,000, 22,000, 24,000, and 26,180 pounds, and released each time to zero. It is seen that under an applied load, the spring deflects uniformly. When, however, the load is released from any of these points, there is no movement of the spring for the first 6,000 to 8,000 pounds, then we get a regular curve, and then a uniform deflection to zero. These springs will balance at any point on the specified load line within the curve. This variation is from $\frac{5}{8}$ to $\frac{3}{4}$ of an inch.

When $\frac{3}{16}$ inch is allowed either way from specified heights, it is apparent that the spring maker has an allowance of 1 inch to $1\frac{1}{8}$ inch instead of $\frac{3}{8}$ inch as intended. The drop of 6,000 to 8,000 pounds, under released load is due to the friction between the leaves.

In the second curve, this friction was plotted by hammering the leaves from point of support to band. The upper dotted line in the curve resulted from hammering the spring under an applied load, the lower dotted line resulted from hammering spring when under released load. It was found possible to reverse this in

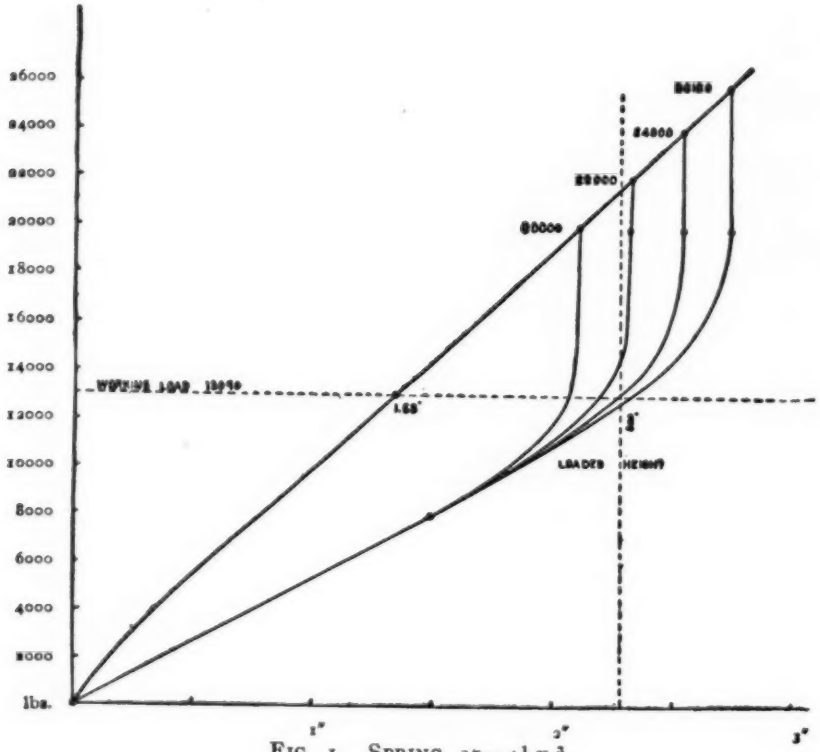


FIG. 1. SPRING, 17—4½ x ⅜.

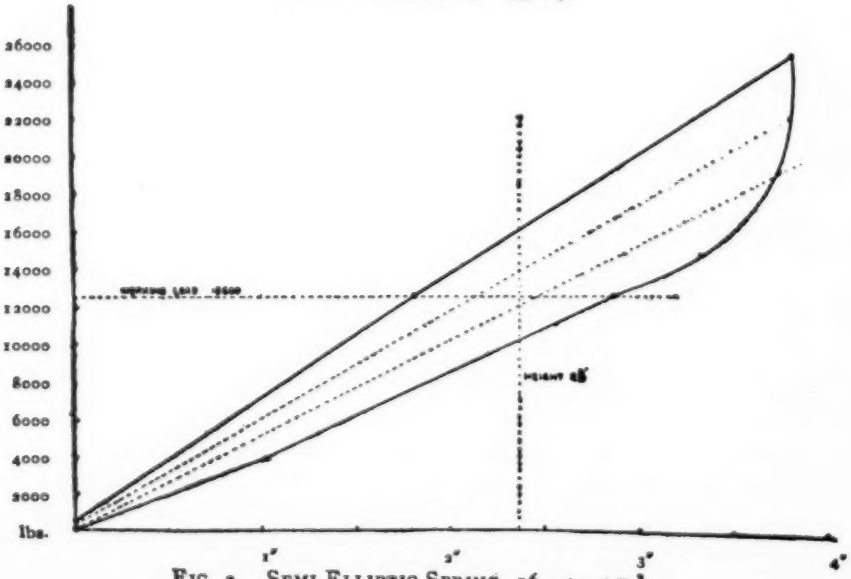


FIG. 2. SEMI-ELLIPTIC SPRING, 16—4—4 x ⅜.

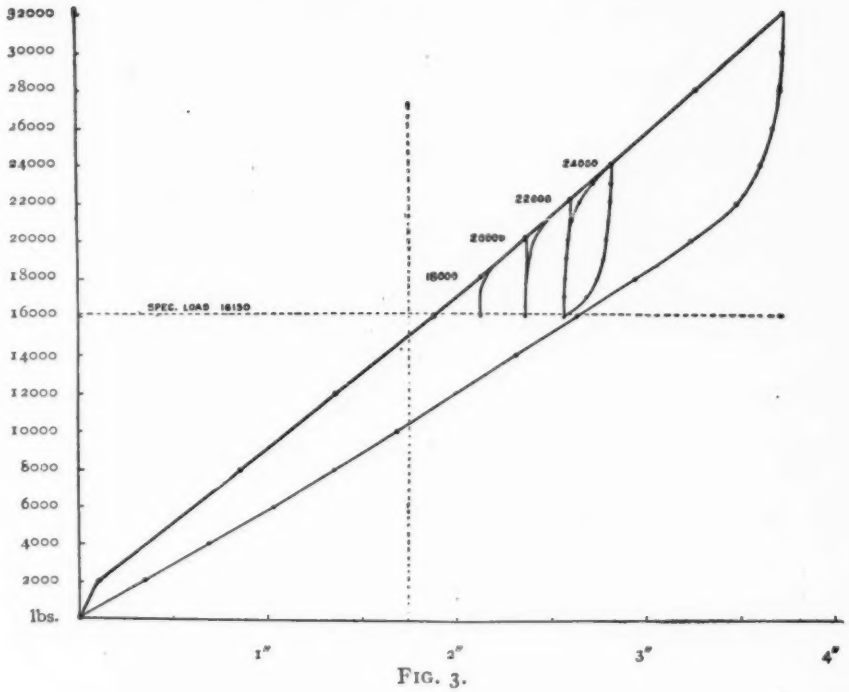


FIG. 3.

10" x 4" x $\frac{3}{8}$"

20"	15000	.65	36"	8320	2.12
22"	13640	.79	38"	7880	2.35
24"	12480	.94	40"	7500	2.60
26"	11520	1.10	42"	7120	2.87
28"	10720	1.28	44"	6820	3.15
30"	10000	1.47	46"	6520	3.45
32"	9360	1.67	48"	6240	3.75
34"	8800	1.88	50"	6000	4.07

30"	10 x 4 x $\frac{3}{16}$	2500	2.93
30"	10 x 4 x $\frac{1}{4}$	4440	2.20
30"	10 x 4 x $\frac{5}{16}$	6920	1.76
30"	10 x 4 x $\frac{3}{8}$	10000	1.47
30"	10 x 4 x $\frac{7}{16}$	13640	1.26
30"	10 x 4 x $\frac{1}{2}$	17760	1.10

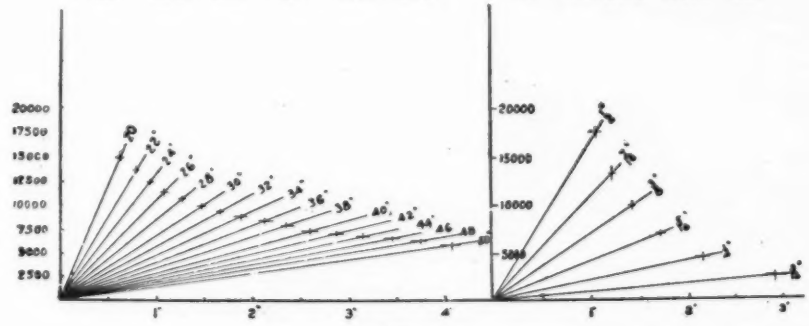


FIG. 4.

either case by hammering the ends of the springs beyond points of support.

In the third curve the action of a spring under an applied load after a partial release, was determined; 24,000 pounds was applied and reading taken every 1,000 pounds down to specified working load and returning. It is seen that the action of the spring is the same when a load is applied from any point on the release load line as when a load is released from any point on applied load line, as might be expected.

From this third curve it is evident that where a spring, tested under an applied load, is put in service at the minimum limit, $\frac{3}{16}$ inch low, upon the application of a few excess loads resulting from turn-table or frog points, it may then be $\frac{1}{2}$ to $\frac{5}{8}$ inch too low. In case of an end spring, cross equalized only, the end of the engine would be too low and necessitate replacing the springs.

From records of broken springs, it appears that some of the failures are due to excessive load per inch deflection or stiff springs, sudden shocks not being properly distributed, throwing most of the strain on certain plates which fail early. Two instances have been presented, one a spring, showing 20,000 pounds per inch deflection and the other 18,000 pounds. These failed continually in service and were replaced with springs of 3,000 pounds less capacity which gave 12,000 and 13,000 pounds per inch deflection and are giving perfect service. This leads to the conclusion that a maximum limit per inch deflection should be established from records of defective springs. It may also be found advisable to establish a minimum limit per inch deflection.

The fourth point shows the effect of varying the length center to center in a spring of 10 plates 4 by $\frac{3}{8}$ in., and varying the thickness in a 30-inch spring of 10 plates 4 inches wide. By changing the thickness, width, and number of plates, the load per inch deflection may be varied at will. The figures given are calculated loads and deflection per Henderson's tables, published by American Society of Mechanical Engineers.

The Committee has not plotted results of surging tests on a long lever machine. The great increase in tonnage has made the short beam, quick acting machine a necessity with spring makers.

Respectfully submitted on behalf of the Committee,

J. A. KINKEAD,
Chairman.

DISCUSSION.

Mr. H. DeH. Bright.—I should like to ask if the committee will make any recommendation as to the best method of testing springs, namely, the straight line test as against the surging test, inasmuch as so great a difference exists between the application of the load, when the load is applied on the up-run, and when it is applied on the down-run. **Mr. Bright.**

Mr. J. A. Kinkead.—The object of the committee is to get a specification in which we can use the rigid motion. The swaying motion has gone out of use, on account of the time it takes in making the test. The exigencies of shop conditions have made a great increase of speed necessary. I believe none of the springs now in use are tested on swaying beam machines, the rigid beam being used instead. Some railroads are at present testing springs at one and a half times, some at twice the load, then taking the height at specified loads returning, and allowing $\frac{3}{16}$ inch each way. The American Locomotive Company take one and a half times the specified load, and allow $\frac{3}{8}$ inch below, but nothing above the specified height. A spring tested in this way will always stand higher than test heights in service. **Mr. Kinkead.**

THE CORROSION OF STRUCTURAL STEEL AS AFFECTED BY ITS CHEMICAL COMPOSITION.

By J. P. Snow.

It is probably not necessary to present proof that ingot steel corrodes much more rapidly than wrought or cast iron. Recent experiences with structures built some twelve to fourteen years ago, when wrought iron bridge material was going out of use, has brought the matter to the writer's attention with such force, however, that it seems worth while to present the salient features briefly, and to try to get this Society to investigate the subject and possibly develop a remedy.

The structures referred to were built partly of steel and partly of wrought iron. One class is signal bridges in which wrought iron and steel were allowed indiscriminately. After a dozen years of service with rather indifferent care as to painting, it was found that some parts were entirely gone, other parts reduced to lacework and other parts uninjured by corrosion. A pair of lateral brace angles, for instance, crossing each other would present the astonishing spectacle of one angle completely rusted through and the other only slightly specked. The painting and all conditions of exposure and protection were exactly alike for both; and it was surmised that the well-preserved parts might be iron and the others steel. Examination of fractured specimens proved this to be the case. Innumerable examples might be given from American and European practice to show that steel made by the boiling process rusts much more readily than puddled iron; but the fact will probably be admitted without contest. Signal engineers find it necessary to use wrought iron pipe in place of steel for connecting rods and roadmasters and farmers complain bitterly about the rottenness of fence wire.

Now what is the cause of this difference? It cannot be wholly due to structure, to the fact that wrought iron is composed of fibers of iron encased in slag envelopes, for cast iron

has no such protection and it does not corrode so freely, even, as wrought iron.

The difference must arise from the chemical composition of the metals. There is some evidence to show that manganese is the guilty element; also that phosphorus retards corrosion. I am not prepared to say with positiveness just what causes the trouble or what the remedy is; but I feel that this Society should make it the duty of some committee to study the problem and report its findings.

It must certainly be easy to determine experimentally, what accelerates and what retards corrosion, provided samples of ferric metals of different compositions can be obtained. The formulation and enforcement of a remedy may not be so easy.

Manganese is used by manufacturers as a convenient alterative. Its use cures certain difficulties in the manufacture of steel, but if it leads to such excessive corrosion as we sometimes meet with, it will be profitable to use metal free from this element, in certain situations, even if it costs considerably more per ton.

If low phosphorus opens the way for corrosion, our basic steel will need attention. Some ingredient must be found that will prevent oxidation and preserve toughness at the same time.

With this short introduction of the subject I leave it to those who are better posted than I am, for discussion and possible solution

THE ELECTROLYTIC CORROSION OF STRUCTURAL STEEL.

By Maximilian Toch.

Engineers have commented publicly on the electrolytic corrosion of structural steel, particularly those parts known as "*Grillage Beams*," supporting columns and base posts, which are either in the ground or surrounded by concrete and partly above the ground, with a view of determining beyond question at which of the poles corrosion occurs, and whether one pole is more active than the other. A series of experiments were started since the last meeting and definite results have been obtained.

The first experiment was performed, as in Fig. 1, by taking two sheets of high grade watch spring steel, which is extremely susceptible to corrosion, and connecting them with the ordinary bluestone telegraphic cell. A volt ammeter was placed in the circuit and the two pieces of steel buried up to 5 in. in sand. Careful observation was made every day to see that the current was uniform, and the sand was first moistened with salt water and then continually moistened with distilled water so that the same strength of salt solution was maintained. This experiment was conducted for 100 days, and assuming that the current travels from plus to minus, or from anode to cathode, the anode being connected with the copper and the cathode being connected with the zinc, corrosion was noticed almost immediately at the anode, and the plates showed violent corrosion at the anode and practically no corrosion at the cathode. These plates shown in the illustration indicated some slight corrosion on the cathode, which, however, was principally chemical corrosion.

The strength of the current was .05 of a volt and the distance between the plates, varying in the damp sand, was $1\frac{1}{2}$ inches, and the amperage varied from .02 to .05.

The current was measured by a "Pignolet," direct reading, continuous current volt-ammeter, and the amount of current, which produced this corrosion was exceptionally small.

The next experiment was tried exactly in the same manner, for a shorter period of time, but instead of using two plates, three plates were used, the third one being designated as the "free" plate, in which chemical corrosion had full sway. At the end of six days these plates were removed, the anode, as shown in Fig. 2, showed marked corrosion, the cathode plate showing practically no corrosion at all, and the "free" plate showed a fair average between the cathode and the anode, and it can

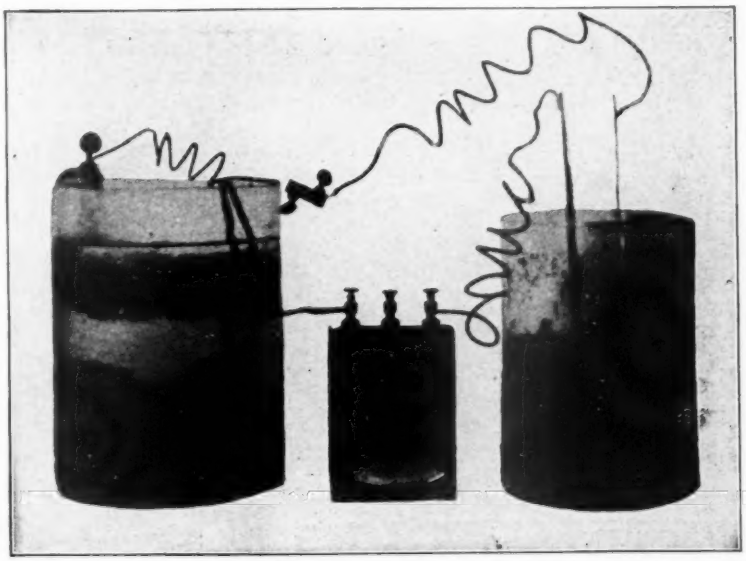


FIG 1.

be deduced that the difference between the cathode and the anode corrosion is equal to the "free" corrosion. In other words, there is many times more corrosion on the anode than there is on the "free" plate, and no corrosion on the cathode plate.

The plates were very carefully varnished all over, in order to preserve them after the experiments were completed. The rust first produced was the green ferrous oxide, $Fe(OH)_2$, which, being a very unstable product, was quickly converted in the air into Fe_2O_3, $N(H_2O)$.

The current was .1 of a volt and .1 of an ampere which

produced this result. The salt solution was four times as strong as that produced in the first experiment.

The third experiment shown in Fig. 3, was, however, of the greatest importance, owing to the fact that the author attempted to imitate the conditions exactly as they existed in buildings. The same kind of steel was taken and bedded in various

FIG. 2.

mixtures of concrete, starting from neat cement and going up to 1, 3, 5. There is a well-known law in physical chemistry that reactions which take place with an increase of pressure are retarded by an increase of pressure, and the question has come up as to whether it is possible for steel to corrode when surrounded by concrete, many engineers holding that the alkaline nature of the cement will prevent the corrosion, and others holding that in conjunction with this condition the pressure exerted by the

concrete prevents chemical decomposition. The author is glad to be able to throw some light on this subject, and the following experiment was carried out:

In the first place cement was taken of known composition, agreeing practically with the definition as quoted in the Journal of the American Chemical Society, 1903, Vol. XXV, No. 7, July, when the question of the permanent protection of iron and steel by means of cement was thoroughly gone into. The cement for these experiments was what might be termed the tri-calcic silicate and calcium aluminate. This is in contra-distinction to the

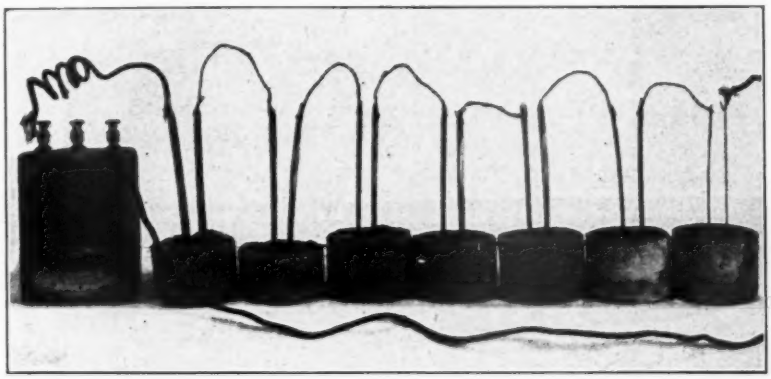


FIG. 3.

general classes of Portland cements, containing dicalcium ferrite as a part of their composition and free calcium sulphate in excess. A cement of the calcium aluminate class, free from iron and free from calcium sulphate, is a well known protector of steel and iron against corrosion, and this class of cement was used in these experiments. The pieces of steel were connected up with six elementary cells of sufficiently high voltage and amperage, and it was impossible to get a direct reading from the volt-ammeter, the instrument being too sensitive. The seven parts of cement, containing the steel strips (see Fig. 3), were then put into the circuit and wet every few hours with solutions of 5 per cent. sodium chloride and 1 per cent. nitric acid, and water, in order to increase their conductivity and produce corrosion as rapidly as possible. The volt-ammeter then gave the following reading:

The average strength of the current was .05 volts and .05 amperes throughout the entire experiment. Corrosion was immediately noticed at the anode pole, and the pat of neat cement which should have protected the steel most perfectly against all kinds of corrosion, showed a hair line split, colored with rust at the end of the third day, which demonstrated that the chemical reaction of rusting had taken place at the anode; that the molecular increase had likewise taken place, and the pressure caused by the molecular increase had split the block. The steel in each alternate pat was painted half the length, which was embedded in the cement with an insulating paint of known composition, having a voltage resistance of 625 volts per millimeter. The results obtained after these various briquettes were broken open demonstrated that electrolytic corrosion takes place most violently at the anode unless the steel be coated with an insulating medium. Cement, concrete, or even neat cement, is therefore no protection against electrolytic corrosion, unless the steel be insulated as heretofore mentioned, and there was absolutely no corrosion where coated with insulating material. It must be noted that the cathode in all these experiments was perfectly free from any signs of oxidation.

The result of this entire series of experiments is to prove conclusively that electrolytic corrosion of structural steel embedded in concrete or sand takes place only at the anode and there with great violence; and furthermore, that the cathode is protected by the electrical current. The popular impression that cement is a protector against all kinds of corrosion is fallacious, and that the anode does not only rust very violently but a molecular increase of volume may take place which will split the concrete shell.

Another conclusion arrived at is that the electrolytic rusting of "*Grillage Beams*" of buildings need not be feared if the structural steel be protected by a good insulating material, but the insulating medium should form a bond with concrete.

THE RELATIVE CORROSION OF WROUGHT IRON AND STEEL.

By Henry M. Howe.

On one hand we have the very general public opinion that steel corrodes not only faster but very much faster than wrought iron, an opinion held so widely and so strongly that it cannot be ignored. Smoke does not prove that fire exists; but such strong smoke bids us look carefully for fire. On the other hand, we have the results of direct experiments by a great many observers, in different countries and under widely differing conditions; and these results certainly tend to show that this popular belief is completely wrong, and that on the whole there is no very great difference between the corrosion of steel and wrought iron. Under certain sets of conditions steel seems to rust a little faster than wrought iron, and under others wrought iron seems to rust a little faster than steel. Thus taking the tests in unconfined sea water as a whole, wrought iron does constantly a little better than steel; and its advantage seems to be still greater in the case of boiling sea water. In the few tests in alkaline water wrought iron seems to have the advantage over steel; whereas in acidulated water steel seems to rust more slowly than wrought iron.

We, as technical and scientific men, naturally attach greater weight to the numerical results of careful direct comparative tests than to rumor and popular belief. When ultra conservative engineers used to cry out against steel boilers, it seemed to us like the old cry "Great is Diana of the Ephesians". Those who raised the cry, cried what they firmly believed was true, and what they thought every sensible man knew to be true. But they were wrong; and I need not tell this Society that such cries and popular beliefs, even when widely and firmly held, often prove wrong. Compared with the results of direct comparative tests such beliefs have the great disadvantage of lacking all precise and definite foundation; they are easily spread from man to man. The fact that steel has come into wide use simultaneously with a great increase in the sulphurous acid in our city air and of strong electric

currents in our city ground, may well lead the practical man, be he hasty or cautious, into inferring that the rapid corrosion of to-day is certainly due to the new material of to-day, steel, whereas in fact it may be wholly due to the new conditions of to-day, sulphurous acid and electrolysis.

At the same time, while popular belief has the disadvantage of lacking direct numerical comparative data, it has the very great advantage of being based on the actual conditions of use, more closely, and often far more closely, than our direct comparative tests are, unless these are planned with very great care.

In view of this great discrepancy between popular belief and the results of our direct tests, it behooves us who have relied chiefly on these latter to examine their conditions carefully, to see whether they really have represented fairly the conditions of actual industrial use and service, in such a way that, if there is a real difference between the corrosion of steel and that of wrought iron, such a difference would become manifest. In short, have our direct comparative tests been trustworthy?

Now, when I review our conditions in the light of this apparent contradiction between popular belief and the results of our direct tests, I am forced to admit that most of our results are not trustworthy in two very important and simple respects which are easily overlooked.

The first is that we have been determining the loss of weight by rusting, in ounces or grammes per unit of surface. We have gone like sheep over a fence. We have generally taken no account of the chief alleged defect of steel, its pitting. It may be perfectly true that steel rusts more slowly than wrought iron, if we measure the rusting by the loss of weight measured over the whole surface of the specimens tested; and at the same time it may be true that, though steel thus rusts less, steel may rust worse, if its rusting takes place in important part by pitting. It seems to me that most of our direct experiments have not taken sufficient account of this difference; and indeed exact comparative data as to pitting are not easily arrived at.

But if steel pits more than wrought iron, this will probably prove to be a defect, not of steel as a whole, but of certain defective steel, viz: steel with surface and subcutaneous blowholes, or with imperfectly distributed manganese.

The second respect in which most of our results are untrustworthy is that they are based on too short exposure to rusting. In many cases they represent only a few months: in very few cases do they represent years. They really ought to be pushed to destruction, that is to say, until either the steel or the wrought iron has rusted through, or so deeply as to be unserviceable.

The reason for this is easily seen when we come to ask, "What are the differences between steel and wrought iron which ought to cause a difference in their rapidity of rusting?"

There are three prominent differences: (1) blowholes, (2) manganese, and (3) the presence of cementite in the steel and of cinder in the wrought iron. Let us take these up in order, and see why it is that they require that direct tests should be very prolonged or pushed to destruction.

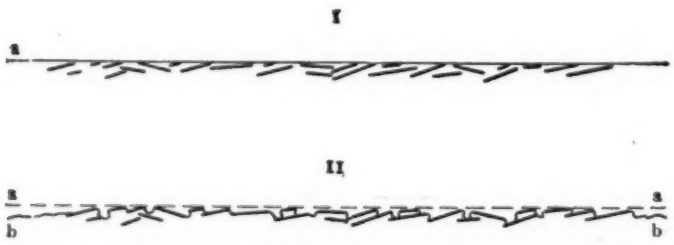
First:—Blowholes exist in steel but not in wrought iron. But blowholes, at least blowholes which do not weld up and thus cease to exist, are not necessary. Yet they are to be prevented only by care and skill. Hence, get your steel only from careful and trustworthy makers.

Second:—Steel always and almost necessarily contains more manganese than wrought iron. This may or may not hasten its rusting. If it does, then its effects ought to be made manifest even in short time tests. From the fact that such tests do not show that steel rusts materially faster than wrought iron, I infer that this manganese is probably not a serious cause of rusting.

Third:—Steel is generally richer than wrought iron in cementite, the iron carbide Fe_3C; wrought iron always contains very much more cinder than steel. Each of these substances, the cementite of the steel and the cinder of the wrought iron, may have a double influence on corrosion, hastening it through difference of potential and retarding it by acting as a mechanical barrier like so much paint, to exclude the oxygen of the air or water. It is not clear that the influence of difference of potential ought to change materially as corrosion proceeds, but it is clear that the mechanical protection given by the plates of cementite and of cinder ought to increase as corrosion proceeds. When a piece of wrought iron, for instance, is first exposed to corrosion, only the outcrops, so to speak, of the sheets of cinder come to the surface: its mechanical protection is very small. But as corrosion

proceeds, and more of the metal which at first overlay the sheets of cinder is eaten away, the remaining cinder forms a larger and larger proportion of the outer surface, and therefore protects a constantly increasing proportion of the underlying metal from corrosion. In short the mechanical protection afforded by the cinder ought to increase as corrosion proceeds.

Here then is a cause which, as corrosion proceeds, should continuously tend to retard the corrosion of wrought iron, and to make it compare more and more favorably with steel. But in like manner, as steel is gradually corroded away more and more of its surface should come to be composed of cementite, and this



Plates of cinder in wrought iron and of cementite (Fe_3C) in steel.

I. INITIAL STATE.—a–a is the surface. The plates of cinder give but little protection.

II. LATER STATE.—a–a is the position of surface before corrosion, and b–b after corrosion. Through the removal of the initially overlying metal, much of the surface consists of plates of cinder which thus effectively protect the underlying metal from corrosion. The thickness of the plates of cinder is very greatly exaggerated, in order to explain the principle.

fact should tend to retard the corrosion of steel, because cementite too should protect the underlying free iron or ferrite.

These causes may in time reverse the initial relative rapidity of rusting of steel and wrought iron. Steel which in the first few months may rust faster than wrought iron may, on greatly prolonging the experiments, or pushing them to destruction, actually rust more slowly: and *vice versa*.

Now of the two, the cinder of wrought iron ought to gain more than the cementite of the steel, in its value as a mechanical retarder

of corrosion, as time goes on and more and more of the metal is eaten away. The reason for this is that the cementite is in such extremely minute microscopic plates that the eating away of a very small quantity of the iron from above them ought to bring very nearly the full proportion of this cementite to the surface; whereas the much larger and more distantly scattered plates of cinder in wrought iron would not constitute their full share of the surface until a much thicker layer of initially overlying metal had been eaten away.

This, then, may be the true explanation. The reason why steel does not rust faster than wrought iron in our direct tests, though it does in actual use, is that our direct tests are too short to bring out the full protective action of the cinder of the wrought iron. Or the reverse may be true. As time goes on, the harmful effect of the difference of potential of the cinder may grow more than its protective action.

Let us therefore henceforth push our tests to destruction.

Two other points: Sheet steel roofing may rust faster than iron because it does not hold the paint so well, and yet steel in other forms, like tubing, may rust no faster than wrought iron.

Again let me emphasize the difference between different steels. Carelessly made steel containing blowholes may rust faster than wrought iron, yet carefully made steel free from blowholes may rust more slowly. Recognize that any difference between the two may be due, not to the inherent and intrinsic nature of the material, but to defects to which it is subject if carelessly made. Care in manufacture, and special steps to lessen the tendency to rust might well make steel less corrodible than wrought iron, even if steel carelessly made should really prove more corrodible than wrought iron.

GENERAL DISCUSSION.

Mr. Howe. THE CHAIRMAN (MR. H. M. HOWE).—Gentlemen, steel has the misfortune to be called steel, whatever its composition; and we must not forget that there is less difference between wrought iron and the steel which is used for tubing, such as boiler tubes, etc., there is less difference between them than between that steel and the steel that is used for high carbon knife and spring steels, of which we have just heard. We must discriminate, therefore, between steels. Not all steels are alike.

The effect of zinc, of course, is a very protective thing. The danger, however, of relying on small scale experiments for our belief in respect to zinc, is that we have to fear that that protection would be very local, because experience alone could tell how far we could depend on it; and while it is distinctly effective for a short distance, I think it has not been shown that it would be effective for any long distance. Of course we might place pieces of zinc at very short distances along the beams and joists, but after the zinc had oxidized it would be of no effect. But it seems to me any impermeable coating of asphalt or whatever it might be, a mechanical coating, ought to last forever.

Mr. Cushman. DR. ALLERTON S. CUSHMAN.—Mr. Chairman, I would like to go on record as stating that I believe that the cinder in wrought iron has a good deal to do with the protection of that metal from corrosion. I am going to begin by discussing the effect of electrolysis on the corrosion of iron and steel. When I was an undergraduate student I made what I thought was a discovery; I soon found, however, that it was not. I found that by taking two steel needles from the same package and attaching them to wires which led to a galvanometer and then inserting the needles in a solution of an electrolyte, that the galvanometer showed a deflection, proving that there was a difference of potential established between two steel needles taken from the same package. If the needles were physically and chemically exactly alike, there should be no difference in potential. The trouble is, no two needles are exactly alike. If that is so, how much more must the difference be in large

steel structures that are made up of a number of separate units. I mean by that, a building of steel construction and the consideration of protection from oxidation of the structure that would be established by erecting zinc anodes in the neighborhood of the building. I am perfectly willing to believe that the zinc anodes would be very rapidly oxidized, but it seems to me that very little effect upon the building as a whole would be obtained, because it stands to reason that in a structure of that sort there must be local differences in potential. I believe that differences in potential in what might be called a physically homogeneous piece of steel or iron, like a strand of wire, are continually being established, when it is wetted with an electrolyte, if the wire is not chemically homogeneous in structure. I admit that the differences of potential are extremely minute, but if they are long continued there must be continually formed points of attack where the chemical action takes place and oxidation begins. Thus weak points are formed where oxidation goes on rapidly and leads to pitting. **Mr. Cushman.**

This may sound speculative, but it can be shown that there are differences of potential established in wires, that are stretched or bent and wetted with electrolytes. Electrolytic corrosion is due simply to local disturbances of equilibrium; and I do not see how we are going to get any protective effects by considering a structure like a building as a cathode. It seems to me to be perfectly impossible.

Now to go on to the subject of the relative corrosion of iron and steel, I confess that I have very little to say. I am not a friend of steel as against wrought iron, nor a friend of wrought iron as against steel. The question that undoubtedly interests every metallurgist, is the underlying reason for the great differences that are observed in service. There can be very little question, I think, that no two kinds of steel will be equally resistant to corrosion whether the test is in the open or in the laboratory. I have in my laboratory two samples of wire made by the same concern. They are both Bessemer steel wires. Yet these two wires will show great differences, in short time tests, in the relative rate of corrosion. It is, however, quite true that it is not necessarily the rate of oxidation but the kind of oxidation which is of the utmost importance. One metal may soon become covered with a protecting coat of oxide, while another may become pitted to the point

Mr. Cushman. of destruction. In my opinion there is no subject that is more important to-day to the practical metallurgist, as well as the man who is interested in it purely as a scientific problem, than the corrosion of iron and steel. And I do not think really that any of us, either in this country or abroad, know a great deal about it yet. I think it is a subject that has got to be systematically investigated and without bias. I do not think it is a subject that ought to be investigated in order to show that wrought iron is superior to steel, nor do I think it ought to be gone into for the purpose of demonstrating that steel is superior to wrought iron. Those are questions that must be determined by the facts in the case as we go along. Why is it that two steels—leaving wrought iron out of the question for a minute—differ so diametrically in the way that they rust and in the rate of their rusting? I have been led to believe that the impurities that exist in all steel, or nearly all steel, have a good deal to do with the question. Manganese is well known to affect the electrical conductivity of steel to a considerable degree. If the manganese is not evenly distributed throughout a long piece of metal it is possible that differences of potential will be established, if the metal is subjected to the action of water. If there are differences of electric potential, naturally currents will flow at the expense of something, and it must be at the expense of the metal which is corroded thereby.

Mr. Christie. MR. JAMES CHRISTIE.—I shall confine my remarks to the subject of corrosion of sheet metal, and while I have no recorded data of experiments, I can refer to the frequent complaint, so widely expressed, that the sheet metals so extensively used for roofing and sheathing do not now, when steel is used, give as satisfactory endurance as when sheets were rolled from puddled iron. It is quite true, as Professor Howe has stated, that we cannot rely entirely on popular belief which may be based on insufficient or unsatisfactory evidence, nevertheless, when this belief finds widespread expression, and is sustained by numerous observations, we must give credence to popular assertion, or else disprove it. Within my own field of observation I can point to roofs covered with sheet iron which have been in existence for periods of twenty to thirty years, with a promise of further longevity, while under apparently similar conditions, steel sheets have become so corroded as to be unfit for service, in half the period. This is not only

the case with the black or uncoated sheet, but appears to apply also to tinned and zinc-coated metal. In fact, it is now generally considered as useless to apply the uncoated metal for roofing purposes, whereas in past times the use of black sheet metal was quite common. Believing these to be facts so far as sheet metal is concerned, yet we are not sure that the same conditions exist when metals of greater thickness are used, and this might appear to be anomalous or inconsistent. Mr. Christie.

Some experiments have sustained the view that initial corrosion is more apparent with steel than with puddled iron, but after superficial corrosion has occurred, some degree of protection is afforded to the underlying metal, which tends to confer equality between iron and steel.

This, if correct, would account for the anomaly, if it exists, as a superficial corrosion would destroy very thin sheets, which would have comparatively little effect on thicker material.

It would appear probable that the cinder contained in puddled iron would protect the metal from corrosion to some extent, considering that this cinder is largely metallic oxide, and ordinarily occupies from 1 to 2 per cent. of the total bulk.

Another illustration is afforded in the susceptibility of the metal to oxidation at high temperatures. When iron was highly refined, that is, subjected to repeated heating and rolling, and much of the cinder contained in the original puddled bars expelled, the welding property of the metal was impaired, or, as the old-time blacksmith said, it became too dry, and burnt readily at the welding heat. The smith had then to use a protecting flux of sand or borax, and when much welding was required, highly refined metal was objectionable.

The constant loss involved in the corrosion of iron, and the expense incurred in the frequent application of protective coatings, form the principal objections to the use of the metal for many purposes to which it is otherwise well adapted.

It would appear to be a promising and not impossible quest, for the metallurgist, to seek for material which if combined with iron will confer some protection from corrosion without impairing the physical properties of the metal or unduly enhancing the cost of its production.

MR. MAXIMILIAN TOCH.—In reference to the criticism that Mr. Toch.

Mr. Toch. has been made on the making of the zinc anode in the case of electrolysis in a building, I simply want to add that the experiment is feasible. I do not contend that it is practicable; and as I have stated in my remarks, it is not original with me, but original with Mr. Hering, President of the Electro-Chemical Society, and in an experimental way it proved a perfect success. And, therefore, both Mr. Hering and I have the advantage over those who have not made the experiment. If a building should show electrolytic corrosion, the question is whether a few tons of zinc should not be employed to save it in preference to permitting the steel to disintegrate.

I wish also to add, Mr. Chairman, on the question of the difference between cast iron and steel, I should be very glad to hear an expression from some chemist who is connected with a steel works, or some engineer who has a practical and theoretical experience on the subject, what his information is on the coating, the natural skin, on cast iron, as compared to steel. In all the sections which I have made of cast iron, and in all the analyses, I have found that on the outer surface of cast iron a sub-oxide or a silicate of iron is formed that completely prevented corrosion. I recall that quite a number of years ago—perhaps twelve or fifteen—when I first was interested in this peculiar difference, that the cast iron bases of the columns that support the Sixth Avenue Elevated Railway in New York, in the section between Seventy-second and Eighty-second streets, were remarkably free from corrosion; and any amount of paint that was put on was either washed off or abraded by passing vehicles. It was almost impossible to protect those bases by paint from corrosion; yet they never corroded. I chipped a small piece from one of those bases and the percentage of iron (Fe.) that we got out of it showed that there was a proportion of silica and oxygen on cast iron that does not exist on steel. It is my personal opinion—merely an opinion—that that is the reason why cast iron is very much better protected against corrosion than steel.

The Chairman. THE CHAIRMAN.—The results of experiments on that point are pretty conclusive that the cast iron which resists corrosion so very well in its natural state does not resist it particularly well, any better than wrought iron, after the natural skin is taken off. The reason is very evident. This coating which the metal spon-

taneously forms when it is poured into a mould of sand, is naturally incorrodible. **The Chairman.**

MR. J. P. SNOW.—So far as I have observed, the difference in the corrosion of puddled iron and steel varies under different conditions somewhat as stated by Mr. Howe. **Mr. Snow.**

When steel and puddled iron are subjected to the action of sea water, it seems to me, from what rough observations I have been able to make, that steel resists corrosion about as well as wrought iron.

It is in those structures which are exposed to locomotive engine gases that the difference is most pronounced. There is no question in my mind but that steel corrodes very much more rapidly than iron in that position.

Innumerable examples of all sorts have presented themselves to me, that prove it seemingly conclusively. Two bridges within 500 feet of each other, over the same lines of track, subjected to exactly the same conditions, one of wrought iron, built twenty odd years ago, another of steel, built fourteen or fifteen years ago, show very clearly that the steel bridge rusts much more rapidly; and parts of that particular bridge which happen to be of wrought iron, being loop welded rods, are not affected at all; whereas the steel members are half gone, some of them. It is over the center of the tracks, where the smokestacks discharge, that the action is the worst. It does not seem to me that it can be due to electrolysis, unless those conditions of engine and smokestack produce electrolysis. I am not an electrician, and I do not know exactly what electrolysis may cover; but I know that steel rusts very rapidly under that action and in that condition, while puddled iron resists much better.

MR. F. N. SPELLER.—It seems to me very unsafe to draw general conclusions from the popular opinions which prevail on the relative corrosion of iron and steel. Popular opinions based on general observations unsupported by real comparisons of the two materails are just as likely to be in error as correct, or more so. In the case of tubes and pipe, in which I am more particularly interested, the majority find no difference in life and many of the large consumers who have investigated the matter thoroughly are now buying steel. It would be more conclusive to compare the two materials under the particular conditions for which they were **Mr. Speller.**

Mr. Speller. made, not pipe with corrugated roofing or structural material as is too often done. The steel which is used nowadays in the manufacture of welded pipe is not the steel put into structural material or wire, or of which corrugated roofing is made; nor is the iron rolled into roofing sheets comparable with that put into pipe.

The subject has been approached by some with interesting theories as to why wrought iron should outlast steel when exact data to substantiate this carefully fostered and apparently erroneous impression is conspicuously lacking. Laboratory tests are indicative but not final. They should be followed up by carefully conducted observations under service conditions. However, laboratory tests have taught us that apparent slight changes in conditions have a marked effect on results; hence, in making field observations we should take every care to have conditions the same.

If a man finds that pipe does not last as long to-day as it did twenty years ago he is apt to associate the change with the introduction of steel pipe. A little further thought would show the great change in conditions due principally to electrolysis and sulphurous air and water near our large centers which have, as Mr. Howe has already pointed out, come in simultaneously with the introduction of steel pipe.

The National Tube Co. has already completed a number of service tests covering some years. So far no material difference between iron and steel can be seen even when the test is carried to destruction. Both in field and laboratory tests the wrought iron has been found to pit as badly as the steel and in some cases more so. In pipe lines it has been our experience that where for any reason the pipe has been pitted that the coupling, made of wrought iron, is equally affected.

We frequently find iron and steel pipe intermixed in a line and have never yet seen the case where adjoining pipes showed any appreciable difference in corrosion. Only a general reference has been made to these investigations; details would take up too much time. Our object is to arrive at the facts under each condition where tubes or pipe are used and to encourage others to do the same. Similar investigations have led large users of pipe to see the error of this prejudice against steel and has led them to abandon iron in favor of a safer and cheaper article.

Most of our tests have been made on steel made over a year ago. Since then the National Tube Co. has adopted a process of treating the steel with the object of increasing its resisting power and lessening any tendency to pit. In comparison with standard genuine wrought iron this steel has shown a loss of 15 per cent. less than the iron in hot salt water, which agrees very well with the results cited by Professor Howe on this steel from tests made in his laboratory. Salt water was chosen for these tests as there is enough data to show that it attacks ordinary steel somewhat faster than wrought iron. Service tests of this steel in mine water and other situations have shown it to be superior to wrought iron, showing more uniform corrosion and a longer life. Mr. Speller.

MR. GEORGE SCHUHMANN.—I wish to add only a few words as to actual experience on the corrosion of iron and steel. Mr. Schuhmann.

A few days ago we received a letter from one of our customers stating that in a certain oil field, where the oil has given out, the operators are pulling out the casing, as they are abandoning the wells. They found that after seven years' use the wrought iron casing came out of the wells in such excellent condition that in several cases even the stencil marks were still easily discernible, and that all of the iron casing was fit to be used again, while the steel casing withdrawn from the wells in the same field showed marked signs of deterioration.

In reference to the tests made by Mr. Howe with samples of "Spellerized" steel and charcoal iron boiler tubes: It would be interesting to know what "Spellerizing" consists of and how much of the difference in corrosion is due to the quality of the steel and how much to the "Spellerizing." In other words, how much would the steel have corroded before it was "Spellerized" compared with the corrosion after it was "Spellerized?" In addition thereto we must not lose sight of the fact that the uniformity of corrosion is a very important factor, as has already been pointed out by the Chairman. That is, as to whether the corrosion is spread evenly over the whole surface, or concentrated in a few spots. It does not matter how heavy the pipe and casing is, after a hole has formed, it has lost its usefulness. In order to bring this point out more fully I may have to give away a little trade secret. Some years ago when there were more freak boilers in the market than there are now, some customers wanted many odd sizes of

Mr. Schuhmann. boiler tubes, such as $3\frac{1}{4}''$, $3\frac{3}{4}''$ and $4\frac{1}{4}''$ in diameter, and some of them 24 feet long. We would usually overrun the order so as to prevent changing rolls between turns, and we put the surplus of the tubes in stock. As our warehouse capacity was very limited in those days, many of the tubes were stored outdoors. After given periods we would have a kind of housecleaning in turning the old stock piles over, and if the tubes had corroded so as to affect their appearance we would "warm them up", i. e., give them another run through the furnace without changing the size, the object being to just freshen up their appearance. If the corrosion had progressed somewhat farther, we would "draw them down", i. e., make tubes of smaller diameter and thinner gauges out of them. Soon after that time we began to manufacture steel tubes also, and treated them the same way as the charcoal iron tubes, and when housecleaning time came around we were surprised to find that the steel tubes presented a better appearance than the iron tubes. Large parts of the surfaces were nice and blue, without any rust specks, while the corrosion seemed to be confined to certain spots only, and we were then under the impression that steel would resist corrosion better than iron. The mill superintendent gave orders to "warm them up", but after they had been run through the furnace the furnace foreman reported that the rust spots would not come out. He was then ordered to "draw them down", but these spots were so deep after drawing down that many of the tubes had to be sent to the scrap heap. Now, these tubes had not been weighed before and after exposure to the weather, but I am inclined to believe that if they had been weighed the steel tubes would probably have shown less loss of weight than the iron tubes, and still the corrosion did not prevent the iron tubes from being used again and converted into tubes which to all intents and purposes were as good as new, while the majority of the steel tubes had become worthless.

Mr Cook. MR. EDGAR S. COOK.—I wish to mention our experience with corrugated roofing. Mr. Christie has referred in considerable detail to the difference in life of roofing of the present manufacture, as compared with the roofing made some years ago, when it was exclusively of wrought iron. The Chairman has suggested that possibly the increased percentage of sulphurous acid gas in the atmosphere of the cities, due to the increased use of bituminous

coal, may have some connection with the decreased life of the roofing materials now so generally used. Mr. Cook.

So far as blast furnaces are concerned the conditions as to sulphurous gas have not materially changed during the past twenty-five years or more that I have had charge of the Warwick Iron and Steel Co. In 1880 we placed over our cinder bed adjoining the furnace, a corrugated roof, in order to protect the cinder men from the weather, both as regards exposure to the sun and also to the rain. The structure was erected by the Phœnix Iron Co.; the corrugated sheets for the roof were made by the Alan Wood Iron Co., of Conshohocken. That roof is still there, and it would be in first-class condition provided we had taken proper care of it. The corrugated sheets were rolled from muck bars made of puddled pig iron. We have not had this roof painted for possibly five years, or maybe longer, having but little use for the protection afforded by the roof since substituting ladles for handling liquid slag. This roof is in far better condition to-day than another corrugated roof far removed from the sulphurous acid gas that issues from the furnace when slag is running. This roof has not been in use over five years. It is all pitted, absolutely good for nothing, and will have to be removed. This last roofing material was sold to me as iron; but it was not iron, it was steel, as was proven after we had paid for it.

It is the bad iron, compared with good steel, that has thrown iron into disgrace. Low prices for skelp iron and for sheets, brought about by competition, has been instrumental in increasing the product of so-called iron made by the busheling process, where a lot of miscellaneous scrap of all kinds, largely steel scrap, for the last several years are stuck together and sold in the market under the name of iron. This product will not compare with the skelp iron or roofing material made out of pig iron which has been well puddled.

Busheled iron undoubtedly has its uses, but where durability is required under conditions facilitating the rusting, as exposure to weather, etc., pipe or corrugated sheets should be made from puddle bars, and these puddle bars should be made from good gray forge pig. Of course, good selected wrought iron scrap would undoubtedly be used in connection with the muck bars thus described.

Mr. Cook. We have another roof over a set of boilers erected in 1883. The conditions are precisely the same as pertain to another set of boilers that was erected in 1899, and surrounded with structural work and covered with corrugated sheets. The 1883 roof on one side is perfectly good; on the other side it shows considerable rusting. A large portion of the 1899 roof is rusted so badly as to be perfectly worthless. In 1883 the best quality corrugated sheets were no doubt made of puddled pig iron, care being taken to select a good brand of pig iron, and, of course, all the sheets were exclusively wrought iron.

The sheets of the 1899 roof were undoubtedly made of steel or busheled iron, in which the scrap used consisted chiefly of steel.

Mr. Huston. MR. CHARLES L. HUSTON.—I want to corroborate what the previous speaker said about the use of scrap, inferior scrap. In a roof I have been examining with some interest lately, or the entire sheeting of a building, in fact, which has been going down for some time, one-half of it was built about 1891, which is perfectly good still, the other half was built about two years later, and the sheathing has all gone to pieces. We had to have the roof removed and replaced three times, and finally we put on wooden sheathing and composition roofing. On examining the fractured edge of the material with a magnifying glass, we could not see very much difference between the two. They looked as if they were both iron. But upon analysis we found quite a difference. It is evident that the later material was made by the busheling process, using largely of steel scrap, as indicated by the manganese it contained, so that it gave less satisfactory service than solid steel probably would have given. The sheeting on the original building, built two years before, shows by the fracture four or five successive layers, indicating that it has been made from puddled bar pile. It is in excellent condition and seems likely to continue for a number of years yet.

Mr. How. MR. R. W. HOW.—The influence of mill scale seems to be quite remarkable on a job on which I am engaged. The subway roof material was to be surrounded by concrete and was shipped from the shops without painting, without any covering whatever. There is a lot of 42-inch girders, about 5 feet apart, which are in in the roof now, having been erected five or six months. Some of the webs of these girders are absolutely perfect, the blue scale is still

there. Other webs right alongside of them are badly rusted, in fact, entirely covered with a red rust. They had the same treatment, as far as we know, but there might have been some difference in the handling that knocked the scale off, and possibly increased the rusting. The effect of the scale seems to have been largely protective. **Mr. How.**

MR. S. S. VOORHEES.—I think the protective action of the silicate of iron on cast iron is rather clearly shown on cast iron car wheels. Those of us who have had the inspection of car wheels to look after have noticed that the chilled tread where the metal is cast against an iron surface is far more rapidly corroded and oxidized than the web and flange of the wheel where it is brought in contact with the sand of the mold. **Mr. Voorhees.**

THE CHAIRMAN.—Gentlemen, have you said all you want to upon this very interesting and important subject? It seems as if the steel makers had still to convince the community that steel can be made that is not particularly susceptible to rusting. I think they can point to the fact that there is badly made wrought iron that can rust badly. I suppose they will be willing to admit that badly made steel also will rust badly; but it seems as if the burden of proof was on them to convince the users that they can make a steel which will not rust. **The Chairman.**

MR. SPELLER.—Mr. Cushman has referred to irregularities in steel causing differences in potential. He omitted to say whether he has made any similar tests on wrought iron. If local galvanic action has much to do with pitting the cinder in wrought iron, which has a difference in potential of about 0.2 of a volt with the iron, might be expected to have a serious effect in this way, offsetting any protecting influence it may have in breaking the bath of corrosion. **Mr. Speller.**

I noticed some time ago in making laboratory tests that mill cinder had a decided effect in starting pits, whereas plates previously freed from surface cinder oxidized much more uniformly. The cinder which is an essential ingredient in wrought iron would be expected to have more effect in causing local galvanic action than such variations as might arise in composition of steel from the same ingot.

It has been our aim to settle this question by introducing improvements, which will increase the resisting power of pipe steel

Mr. Speller. so as to leave no doubt as to its comparative durability,—its superiority in other respects being already granted.

Mr. Cushman. MR. CUSHMAN.—I should like to add one or two remarks. The question that interests farmers is, why is it impossible to buy a wire fence that will last? The progressive farmer does not want to buy a fence that will be all rusted in two years. Now, investigation will prove that the wires in a woven wire fence, horizontal wires, which come from the same furnace, made by the same process, do not last for the same length of time. That was the first observation I made when I began to look at wire fences. On a wire fence that has been up, say four years, it may frequently be observed that one strand is very rusty from beginning to end, while the other strands may be perfectly good, just as good, in fact, as the day they were put up. Why is it that one of the wires is bad and the other wires are good? We have heard about the segregation of impurities in the ingot from which the wire is rolled. The top may be different from the bottom of the ingot. It is a matter of observation in wire fences that the lower wires, close to the ground, kept wet nearly all the time by weeds in the summer-time and the snow in the winter, invariably last, whereas the upper wires are the ones that go to pieces. This observation is not founded entirely upon what I have seen myself in the field. I have a great mass of documentary evidence, letters written to me by big stock farmers who have miles and miles of wire, stating that the bottom wires remain in good shape and it is usually the upper wires that go to pieces. It may be, as I have suggested elsewhere, that electrolysis is at work, and that the wires that are continually grounded all along the line by wet weeds or by melting snows are earthed and are not subject to the differences of potential that may establish themselves around the loops in the upper part of the fence.

So without returning to the discussion of the relative merits of wrought iron and steel, the fact remains that one wire differs in its resistance to corrosion from another wire of essentially the same metal, made in the same mill.

Mr. Toch. MR. TOCH.—Mr. Chairman, I have to suggest for the furtherance of any knowledge on this subject that if any instrument I have is of any value I will be very glad to loan it to the department, to determine whether it is the reason or not. If the

bottom wires can be entirely cleaned and the upper part corrodes, and a contact made between them and the upper wires, it would be very easy to determine by the potential difference whether there is any electrolysis going on, and if it is, that being the diagnosis, the prognosis would be very simple. **Mr. Toch.**

MR. CUSHMAN.—I have spent a summer in the field with all the necessary instruments, trying to make just such measurements. I found it a difficult problem. The difference of potential established at the junctions which must be made are of a higher order than the differences that exist in the wires themselves. **Mr. Cushman.**

It is probable that these potential differences are extremely minute and are constantly shifting and changing. I have reached the conclusion that little or no information can be obtained in this way.

THE CHAIRMAN.—This observation that the upper wires rust more rapidly than the lower wires is an exceedingly interesting one, and the possible explanation is that when the wire is drawn it leaves the wire die with a certain amount of coating, with the soap or whatever it is on the wire. Now it may be possible that the upper wire, being exposed to more wind and dust, has that protective soap coating rubbed off more quickly by the action of the dust going by than the lower wires, and therefore is sooner left bare than the lower wires. **The Chairman.**

MR. EDGAR MARBURG.—In view of the importance of this subject and the lack of knowledge concerning the same, it would seem to me eminently proper for the Society to appoint a standing committee on the general subject of the corrosion of iron and steel. I move that the Executive Committee be requested to consider the desirability of appointing such a committee. (This motion was carried.) **Mr. Marburg.**

MR. WM. A. NOYES.—There has been very much said about electrolysis, but it seems to me that the distinction between electrolysis which is caused by considerable differences of potential occasioned by currents of street railways and the like, and electrolysis which is occasioned by differences of potential between portions of the steel that are in immediate contact, has not been sufficiently clearly emphasized. I think it extremely doubtful, for instance, in the case of fence wire, whether there can ever be a difference of potential between the top and bottom wires **Mr. Noyes.**

Mr. Noyes. which will affect those wires *en masse*. We all know that if two wires are in contact the difference of potential must reach a certain limit of value, which is usually more than one volt, before any permanent electrolysis will continue. For otherwise there is simply a polarization which balances the tendency to electrolysis. It is only when we get a difference of potential that goes beyond that that the whole mass, the whole wire, for instance, will be rusted or affected by the electrolysis. On the other hand, we have local currents produced by differences in the homogeneity of the material that affect the wire locally, and it is these latter effects that are undoubtedly very much the most important in the actual rusting of steel. I think it has been well pointed out that it is probably the lack of homogeneity in steel which causes it to rust so much more rapidly than iron.

STANDARD SPECIFICATIONS FOR SHIP MATERIAL.

GENERAL DISCUSSION.

Mr. E. PLATT STRATTON.—The rules for ship construction, under the American Bureau of Shipping, which is the leading American Ship Classification Society of this country, were adopted in 1900, the original rules of this Society for ship construction having been originally adopted in 1868. Mr. Stratton.

The standard specifications for ship material in steel plates, angles and shapes, require a tensile strength of from 58,000 pounds to 68,000 pounds per square inch of section, an elastic limit of one-half the ultimate tensile strength, a reduction of area at point of fracture of at least 40 per cent. and an elongation of 22 per cent. in 8 in. for plates 18 pounds thick and over, and 18 per cent. for plates under 18 pounds thick. Material of greater ultimate tensile strength than 68,000 pounds per square inch and not above 70,000 pounds per square inch may be accepted, provided the elongation and reduction are as specified and the bending tests meet the requirements of the rules. Shapes and angles in excess of 68,000 pounds tensile strength per square inch, must also be capable of being efficiently welded. Bending specimens for all material must stand bending through 180° on a radius of half its thickness, without fracture on convex side, either cold or after being heated to cherry red, and quenched in water at 80° Fahrenheit. A sufficient number of tests must be furnished the inspector to properly represent the material. The number of tests required and the method of selection will be left to the judgment of the inspector, but in no case shall there be less than one test from each heat. Short specimens of angle bar to be flattened out cold and afterwards doubled up so that the ends of the angle bar meet without showing signs of crack or fracturee.

In order to further test the quality of steel angle bars, samples, after being heated a medium bright red, to be turned to form a quarter circle, the inside radius of which is not to exceed three and one-half times the width of the narrow flange of the bar, and the flanges are to be flattened out, or doubled in, until the edges meet

Mr. Stratton. without showing signs of cracks or fractures, otherwise the material from which the samples were taken to be rejected.

The efficiency of steel rivets to be tested by having samples of short rivets flattened into their heads, and long rivets doubled over until the point touches the neck. If the samples fail to undergo these tests satisfactorily cold, the lots from which they were taken to be rejected.

In this connection, I would state that it is now a matter for the future consideration by the Bureau of adopting rules for the test of rivet bars, prior to their being manufactured into rivets or stays.

Makers of steel castings are required to submit for test two pieces prepared by them from the pouring of each casting, one of which should show a tensile strength from 60,000 to 75,000 pounds per square inch of section, and an elongation of at least 15 per cent. in 8 in. the other piece to be submitted to a cold bending test to an angle of 90° without fracture, each piece of stem, stern frame, rudder frame or other casting to be hoisted up and subjected to a shock due to a fall of 15 feet on hard ground, proper discretion being observed by the inspector according to the shape and weight of the different castings, so as not to subject any unnecessary or concentrated strain on any light or particular part. All castings to be subsequently suspended and subjected to a surface examination, and hammer test, the size of the hammer to be proportioned to that of the casting, but in no case to exceed twenty pounds in weight, in order that the surveyor may satisfy himself that the castings are without flaw and perfectly sound throughout. Steel forgings for hull construction shall have a tensile strength of not less than 55,000 pounds nor more than 65,000 pounds per square inch of section, and an elongation of at least 20 per cent. in 8 in.

All the rules of this Bureau alike apply to both steel and iron vessels in all that relate to methods of construction, the scantlings of the iron vessels being about 20 per cent. heavier than those of steel vessels.

All plates of iron are required to be of the best brand, tough, malleable and stamped with the maker's name; the surfaces to be free from flaws and blisters, and the punchings free from cracks on the convex side; brittle or a coarse crystalline

iron must not be used. The absolute mean breaking strength to be not less than 48,000 pounds per square inch and all plates to bend cold to the following angle: Mr. Stratton.

Under $\frac{4}{16}$ths of an inch, with the grain 100 degrees, across the grain 40 degrees.

From $\frac{4}{16}$ths to $\frac{6}{16}$ths, with the grain 75 degrees, across the grain 30 degrees.

$\frac{6}{16}$ths to $\frac{8}{16}$ths, with the grain 50 degrees, across the grain 20 degrees.

$\frac{8}{16}$ths to $\frac{10}{16}$ths, with the grain 35 degrees, across the grain 15 degrees.

$\frac{10}{16}$ths to $\frac{12}{16}$ths, with the grain 25 degrees, across the grain 11 degrees.

$\frac{12}{16}$ths to $\frac{14}{16}$ths, with the grain 15 degrees, across the grain 8 degrees.

$\frac{14}{16}$ths to $\frac{16}{16}$ths, with the grain 10 degrees, across the grain 6 degrees.

Angle bars to be free from veins and cracks or laminations. Iron forgings for hull construction shall have a tensile strength of not less than 45,000 pounds, nor more than 55,000 pounds per square inch of section, and an elongation of 20 per cent. in 8 in.

Steel to be used in construction of marine boilers is required to fulfil the following conditions:

Process, open hearth.

Shell:—

Phosphorus, not more than .04 of one per cent.
Sulphur, not more than .04 of one per cent.

Fire box:—

Phosphorus, not more than .035 of one per cent.
Sulphur, not more than .035 of one per cent.

Tensile strength:—

Rivet steel, 45,000 to 55,000 pounds per square inch.
Fire box, 52,000 to 62,000 pounds per square inch.
Shell steel, 55,000 to 73,000 pounds per square inch.
Brace and stays, 55,000 to 65,000 pounds per square inch.
Tubes, 52,000 to 62,000 pounds per square inch.
All other steel of 52,000 to 62,000 pounds per square inch.

Mr. Stratton. Elongation:—

Rivet steel, 28 per cent. in 8 in.
Plates $\frac{3}{8}$ths in. and under, 20 per cent. in 8 in.
Plates $\frac{3}{8}$ths to $\frac{3}{4}$ths, 22 per cent. in 8 in.
Plates $\frac{3}{4}$ths and over, 25 per cent. in 8 in.

Cold Bending and Quenching Tests.—Rivet steel must bend 180° flat on itself, without fracture, on outside or bent portion. All steels of 52,000 to 62,000 pounds of tensile strength, half inch thick and under must bend 180° flat on itself without fracture on outside or bent portion. Over a half inch thick, must bend 180° around a mangrel one and a half times the thickness of the test piece without fracture on outside of bent portion.

Boiler Tubes.—Hydrostatic test to be applied to all tubes by maker. Subjected to internal pressure of 500 pounds per square inch and when under pressure to be lightly hammered, especially on weld (if welded tubes are used). Cold test to be applied to not less than one tube in fifty in the judgment of the inspector. End of tube must allow of being expanded cold by conical drift to 10 per cent. excess on outside diameter. Lengths of four inches to be flattened till sides are close, with weld (if the tube is welded) at the turn of the fold, and without showing fracture. End of tube must allow of being flanged at right angles to the tube, width of flange $\frac{5}{16}$ths in. from barrel of tube, and without showing fracture. Invoices must indicate the kind of material from which tubes are made.

Iron.—Iron may be used in place of steel in the construction of marine boilers, for tubes and for screw stays. In such case, iron must show with the fiber a tensile strength of not less than 44,000 pounds per square inch, and elongation in 8 in. of not less than 12 per cent.; and across the fiber a tensile strength of not less than 40,000 pounds per square inch of section, and an elongation in 8 in. of not less than 8 per cent. The hydrostatic and cold test for tubes and stays of iron are the same as those of steel.

All material in order to be considered in conformity with the rules of this Bureau must be offically stamped "A. B. S." in location where it is not liable to be obliterated or removed.

Forged carbon steel for shafts must fulfil the following tests:

Mr. Stratton.

Tensile strength:—

Not less than 60,000, not more than 70,000 pounds per square inch.

Elongation:—

Not less than 20 per cent. in 8 in., 24 per cent. in 4 in., or 28 per cent. in 2 in.

Bending Tests:—

Bar ½ in. square to bend through 180° around a mandrel 1 in. in diameter without fracture on outside of bent portion.

If it is desired to employ nickel steel or other special steels the case should be submitted to the Bureau for consideration.

Where cast steel is used for propeller bosses and blades, bedplates, engine framing, brackets, levers, cylinder covers, bearing caps, bushes, eccentric straps, pistons, crossheads, etc., the castings must be thoroughly annealed and are to be subjected to such hammer and drop tests as may be practicable.

Drop tests shall be made from a height not less than 10 feet on a hard road or floor.

Where cast steel is used for shaft webs, coupling flanges or other purposes usually requiring forgings, the material employed must also be subjected to tensile and bending tests as follows:

Tensile Strength:—

Not less than 60,000 pounds per square inch.

Elongation:—

Not less than 15 per cent. in a length of 8 in.

Bending Tests:—

For moving parts a bar 1 in. square shall bend cold through an angle of 120° over a radius not exceeding 1½ in., and without showing cracks or flaws. For other castings the test may be the same except that the angle may be reduced to 90 degrees.

Cast Iron:—

All cast iron employed in the construction of marine machinery shall be of standard quality, and the castings must be free from blowholes, shrinkage, cracks or other imperfections which might in any way reduce the strength of material for the purpose intended.

Mr. Stratton. On behalf of the American Bureau of Shipping, I appeared before Committee A at Philadelphia and submitted for its consideration, the rules of this Bureau relating to ship-building, resulting from those adopted when it was established in 1868, which have been re-written and re-adopted in 1900. These rules have, therefore, been fully operative since 1900, and I submit such portion of them as relates to ship-building material for publication in the proceedings of this Association. In behalf of this Bureau, after six years experience with these rules, I suggest their adoption or approval by this Society, they being, we think, the most desirable our organization is able to formulate in the interests of the ship-owner, ship-builder, manufacturer of material and underwriter, they having been generally received favorably throughout the country by all interests concerned. Most of the American material manufactured in this country for ship construction since their adoption has been produced under tests and in accordance with their requirements. What gentlemen representing the manufacturers of material may have to say on this subject, we shall listen to with great interest and respond to in the course of the proceedings.

Mr. Howe. MR. H. M. HOWE.—I should like to make one suggestion as to these specifications. It is in regard to the matter of segregation, the importance of providing that segregation shall be sought for by taking drillings in the part most liable to segregation; that is, the part that represents the axis of the ingot. In important cases especially, where the upper part of the ingot is used, check drillings should be taken from that part of the material which represents the upper part of the axis of the ingot, to determine what the percentage of phosphorus and sulphur and carbon is there. You should have first, certain limits of composition specified for the steel as a whole, for the ladle test; and of course the majority of steel will come pretty near those limits. Then you should have, beyond that, provision for check drillings which shall intentionally, directly and avowedly seek the most segregated and worst part of the material, and then you should have limits for phosphorus sulphur and carbon beyond which that worst part must not go. My proposition is that we should stipulate a degree of badness which we will tolerate for that bad part, and certain limits that we will tolerate for carbon phosphorus and sulphur.

MR. W. A. BOSTWICK.—On this question of ship material, if the Society is considering the formulation of specifications for ship material, it seems to me it would be far better to follow along American lines. The American Bureau of Shipping in this country is a recognized registry. Lloyds is essentially a British registry. If this Society is considering the formulation of a hull material specification, I think considerable attention should be paid to adopting something that is strictly American. There are a good many features about the Lloyds specifications that are adapted to British practice, but are not well adapted to American practice. One thing alone, which may possibly seem a small matter is the method of figuring tensile strengths in the unfamiliar figures, 28 to 32 gross tons, instead of the familiar ones of 58,000 to 68,000 pounds. Mr. Bostwick.

EXPERIMENTS ON THE SEGREGATION OF STEEL INGOTS IN ITS RELATION TO PLATE SPECIFICATIONS.

By Chas. L. Huston.

Ingot No. 1, 9 x 12 In., Weight 900 Pounds.—Tests Were Not Made from This Ingot.

Manufacturers of steel are generally aware of the character of segregation in steel ingots and the part it plays in their various lines of product, but I think users of steel are not generally so well informed, and even many engineers do not understand very clearly just how this segregation lies in the ingots.

The charts give the results of tensile tests and carbon analyses from plates, showing how the steel varies throughout the different parts of the ingots; also showing that under the present standard practice and known methods of manufacture it is difficult or nearly impossible to secure steel that even in one moderate sized plate will have anything like the uniformity generally supposed to exist, because the tensile strength, in almost any one plate of a ton weight or over, will vary 5,000 lbs. or more in tests taken from different parts.

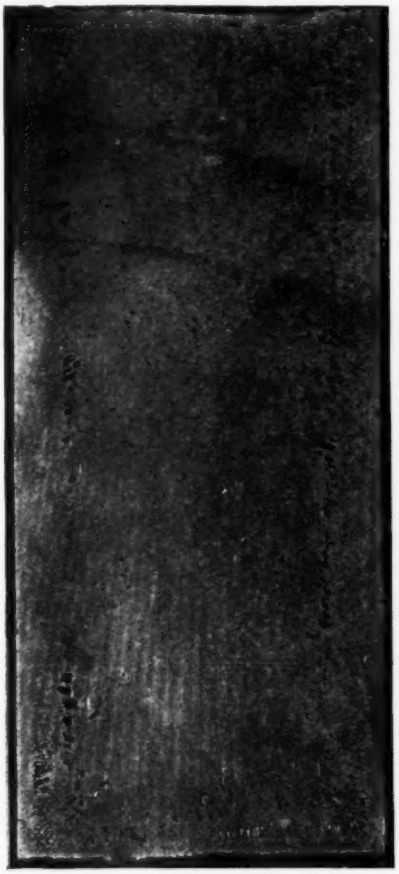
The tests here presented are applicable only to mild or soft open hearth steel, as my experience has been very limited with any other kind, so that these results can be applied only to that class of material.

The photographs were taken from ingots after they had been planed down to their center line and show the char-

Note.—Acknowledgment is made to the *Iron Age* for the cuts used in this paper. Ed.

acter of the interior of the metal. I think this throws some light upon the results shown in the tests hereafter explained.

These ingots are of different shape and weight, purposely



Ingot No. 2, 16 x 18 In., Weight 2800 Pounds.

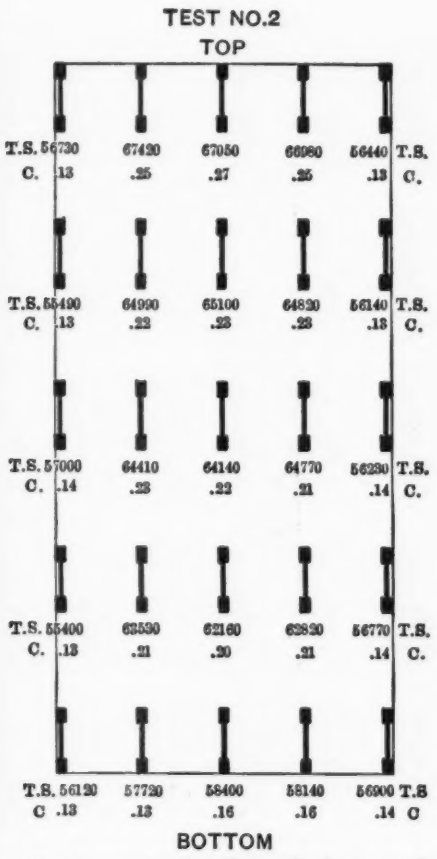
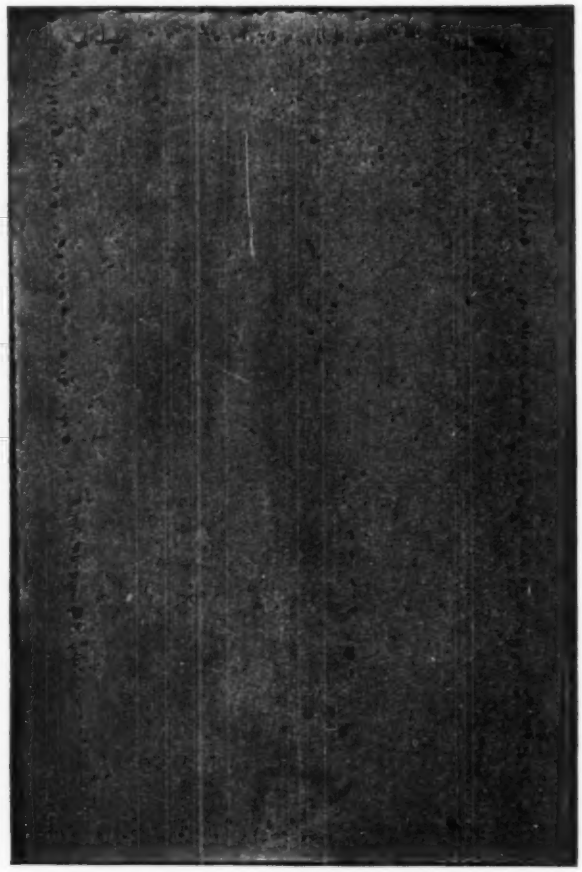


Chart 2.—Ladle Test Carbon, 0.18. Plate Rolled 370 In. Long, 76 In. Wide and $\frac{5}{16}$ In. Thick.

so selected in order to show the difference in the character and extent of the segregation in the different sizes and shapes, yet they show certain general characteristics common to all.

Number 1 photograph is from an ingot 9 in. thick by 12 in. wide, about 36 in. high, weight about 900 pounds, being about the smallest section we use for direct rolling. By some misunderstanding the duplicate of this failed to be rolled for test.



Ingot No. 3, 12 x 26 In., Weight 2850 Pounds.

Number 2 photograph and chart are from duplicate ingots 16 in. thick by 18 in. wide, about 36 in. high, weight about 2,800 pounds each; a size similar to those used in other lines of product

besides plates, such as structural steel, etc. Plate rolled 370 in. long, 76 in. wide and $\frac{5}{16}$ in. thick. Ladle test carbon 0.18.

Number 3 photograph and chart are from duplicate ingots 12 in. thick by 26 in. wide, about 36 in. high, weight about 2,850

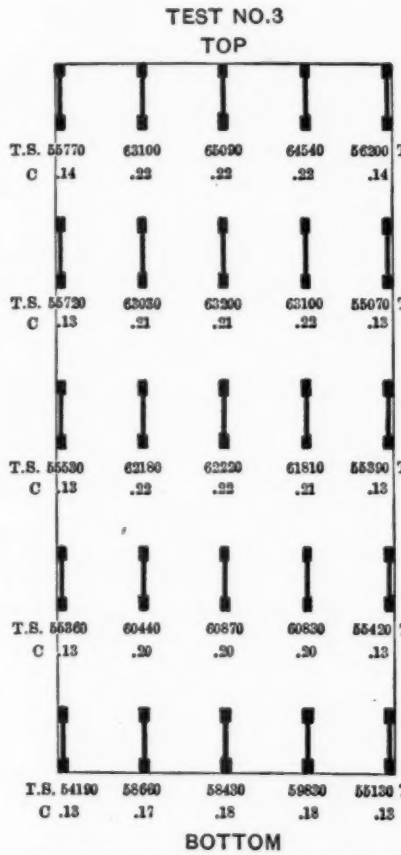


Chart 3.—Ladle Test Carbon, 0.18. Plate Rolled 330 In. Long, 75 In. Wide and $\frac{5}{16}$ In. Thick.

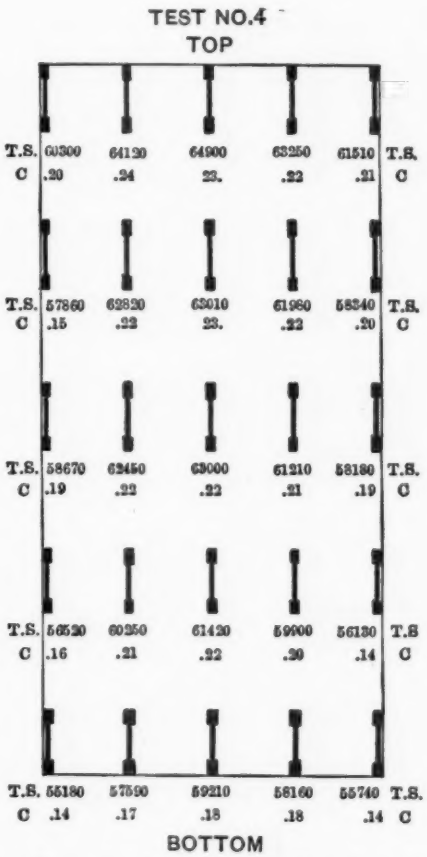
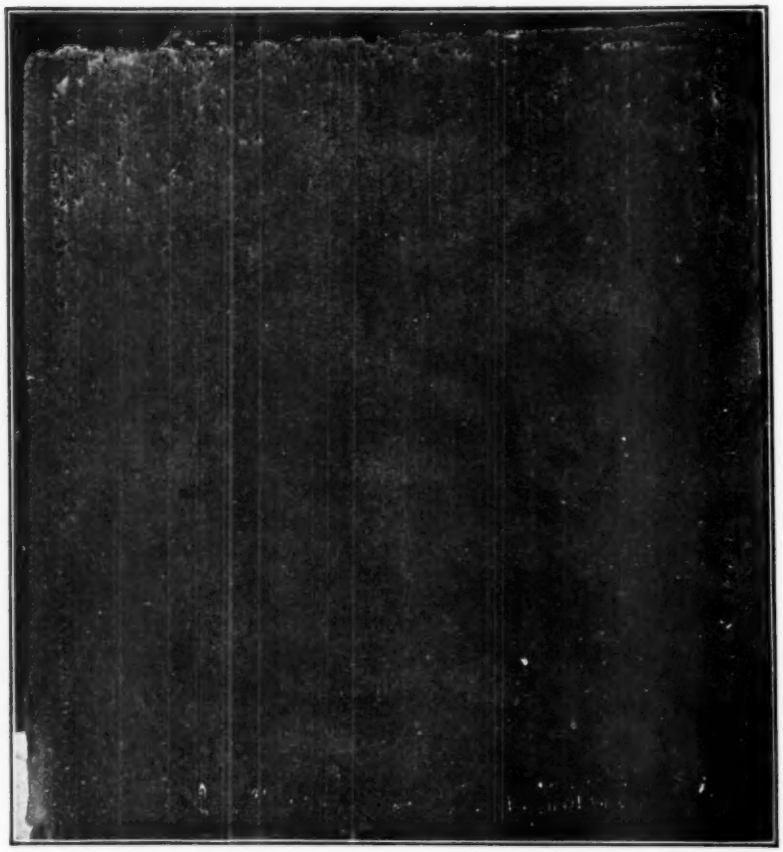


Chart 4.—Ladle Test Carbon, 0.18.—Plate Rolled 350 In. Long, 76 In. Wide and $\frac{5}{16}$ In. Thick.

pounds each; a size we make large use of both for sheared and universal plates. Plate rolled 330 in. long, 75 in. wide and $\frac{5}{16}$ in. thick. Ladle test carbon 0.18.

Number 4 photograph and chart are from duplicate ingots 8 in. thick by 38 in. wide, about 36 in. high, weight about 2,950 pounds each; an unusual size, very thin in proportion to the width, but one we find advantageous in certain classes of work. Plate



Ingot No. 4, 8 x 38 In., Weight 2950 Pounds.

rolled 350 in. long, 76 in. wide and $\frac{5}{16}$ in. thick. Ladle test carbon 0.18.

These four tests are from different shaped ingots, bottom poured from the same melt of steel upon one stool plate, one ingot

of each size being planed for photographic test, and its duplicate (excepting Number 1), rolled into a plate for tensile and chemical test.

Ingot No. 5, 15 x 22 In., Weight 3775 Pounds.

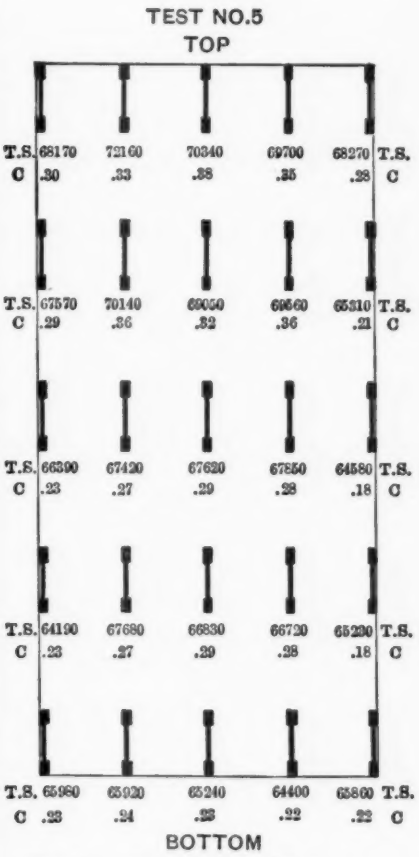


Chart 5.—Ladle Test Carbon, 0.23.—Plate Rolled 378 In. Long, 78 In. Wide and $\frac{3}{4}$ In. Thick.

Number 5 ingot, 15 in. thick by 22 in. wide, about 33 in. high, weight, 3,775 pounds, is, like the 12 in. by 26 in., a size largely used. One-half of it was cut away by planer for the photograph and the remaining half then rolled into a plate 378

in. long, 78 in. wide and $\frac{3}{8}$ in. thick for tensile and chemical test, as given in the chart. Ladle test carbon 0.23.

Number 6 (no photograph of ingot section) was rolled from a large ingot 20 in. thick by 48 in. wide by 50 in. high, weighing

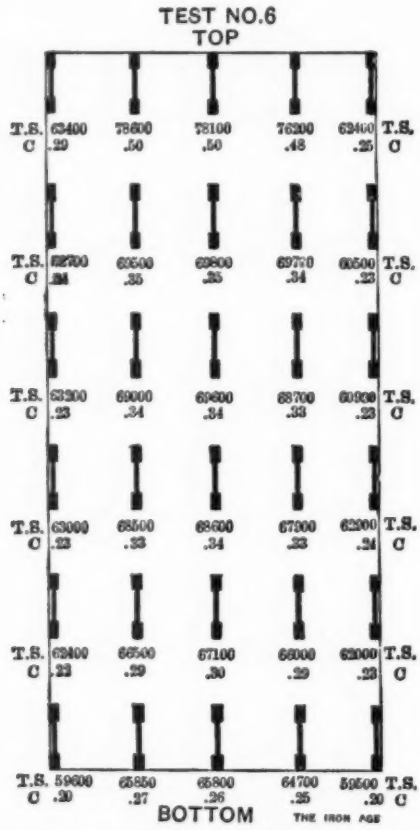
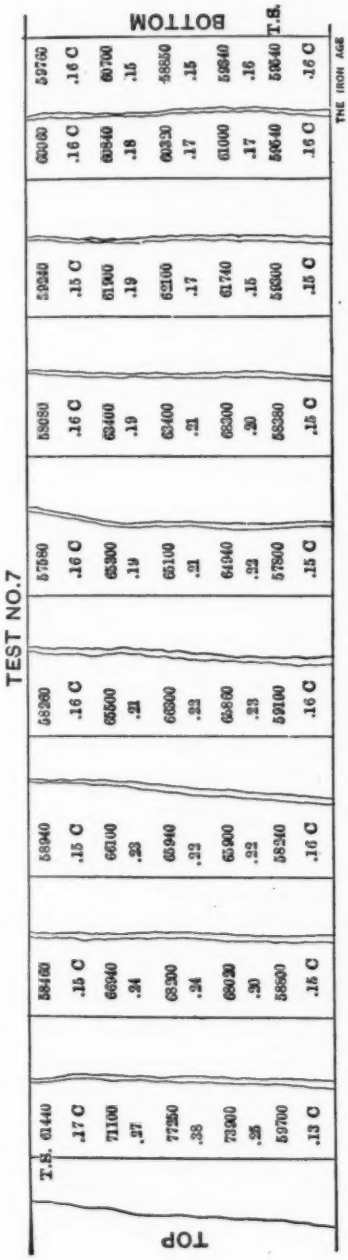


Chart 6.—Ladle Test Carbon, 0.26.—Plate Rolled 335 In. Long, 94 In. Wide and $\frac{29}{32}$ In. Thick.

11,000 pounds and of quality about such as is used in making large plates of heavy gauge for the outside shells of marine boilers where 60,000 pounds tensile strength is desired. This plate was rolled 335 in. long, 94 in. wide and $\frac{29}{32}$ in. thick. Ladle test carbon 0.26.



Number 7 (no photograph of ingot section) was rolled from a large ingot 30 in. thick by 34 in. wide, about 72 in. high, weighing about 18,000 pounds, first slabbed down to 29 in. wide by $3\frac{1}{2}$ in. thick, cut into eight slabs, and these reheated and rolled into plates $\frac{3}{8}$ in. thick, all of one size, for physical and chemical test; the location of the slabs, as they were cut, being carefully noted and traced so as to properly group the tests of the plates in the chart. Ladle test carbon 0.19.

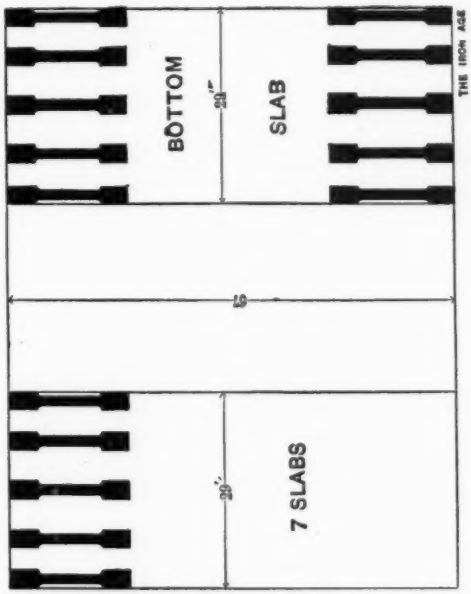
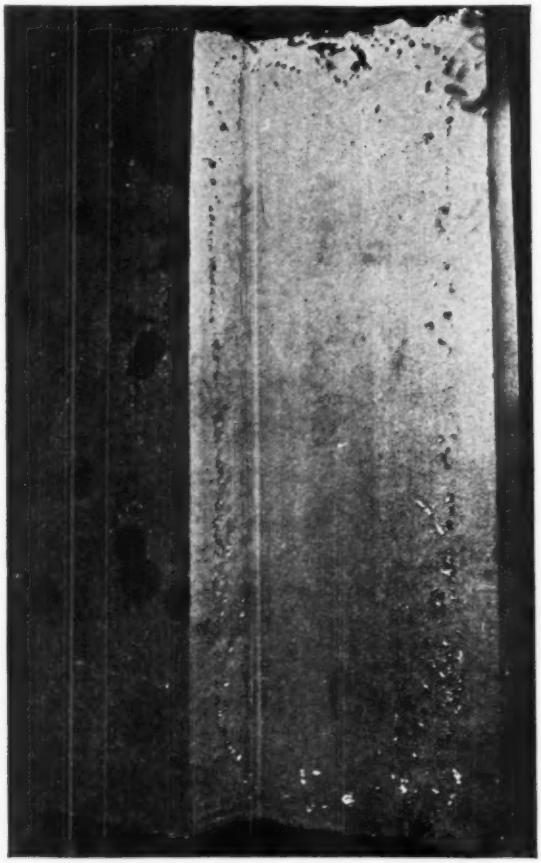


Chart 7a.—Slabs from which Plates were Rolled.—Tests were taken from the Plates as indicated.—Two Sets of Coupons from the Bottom Slab.

Number 8 photograph and chart are from an ingot 26 in. wide by 12 in. thick, about 32 in. high; one quarter planed out longitudinally for photograph, then the other quarter cut away, samples taken from the planed face of the remaining half for



Ingot No. 8, 12 x 26 In., Weight 2800 Pounds.

chemical analyses and finally this half heated and rolled into a plate $\frac{1}{4}$ in. thick for physical test, these tests being located so as to correspond as closely as possible with the location of chemical analyses taken from the center plane of the ingot. Ladle test carbon 0.19.

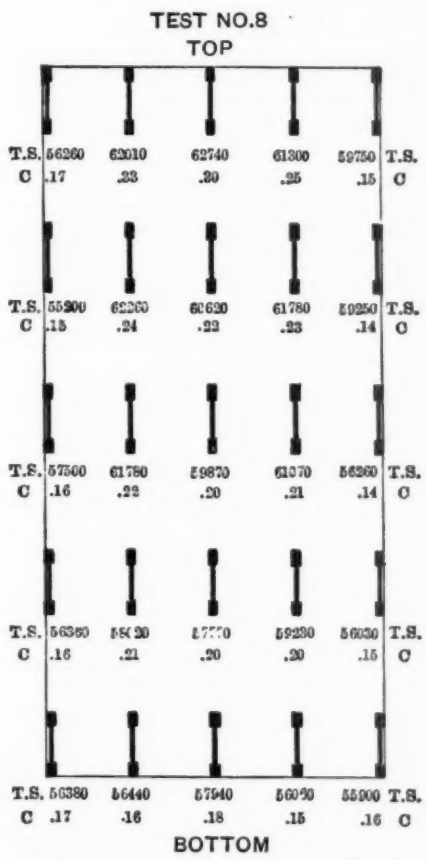


Chart 8.—Ingot No. 8, Ladle Test Carbon, 0.19.—Rolled into ¼-in. Gauge after being Planed Down to ½-in. Thickness.—Carbon Test taken from Center Plane of Ingot.

Number 9 shows the carbon analyses only, from a 15 in. thick slab rolled from a still larger ingot, 30 in. thick by 50 in. wide, about 6 feet high, 30,600 pounds weight; the drillings being taken from the cut ends of the slabs and from the center plane of the metal. Ladle test carbon 0.23.

These last two differ from the others in that their carbon

analyses were taken from the center plane of the metal and hence show greater segregation, while all carbons given in the other

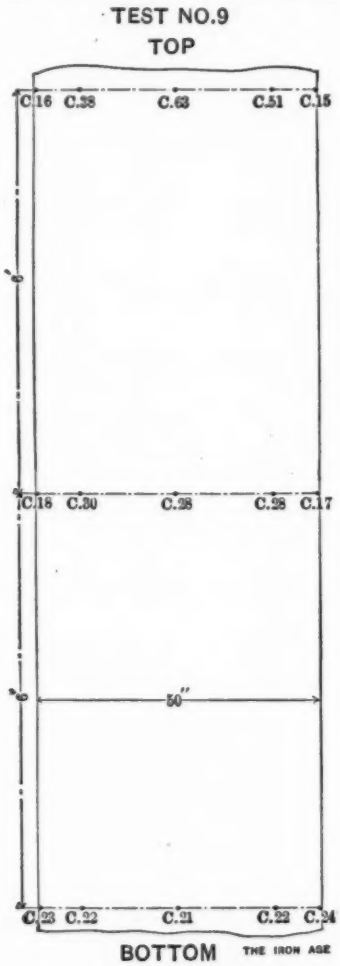


Chart 9.—Slabs from Ingot, 30 x 50 In., Weight 30,600 Pounds. No Photograph of Ingot Section. Ladle Test Carbon, 0.23.—Slabs Rolled 15 In. Thick and 50 In. Wide.—Test Taken from Drillings through the Center of each Cut.

charts were obtained from drillings taken entirely through the plate samples and thus show the chemical test from the same body of metal as used in the tensile tests.

Number 10 shows carbon tests taken radially across the planed face of the 16 in. by 18 in. ingot shown in photograph Number 2, verifying the above theory and in addition showing where the greater segregation lies, viz., just in or inside the zone of gas holes, with very slight differences all the way into the center as further explained below.

Segregation by agreement, I think, of all authorities upon the subject, occurs from two main causes:— One is from expulsion by "selective freezing" of the steel; the steadily accumulating wall of solidified steel at the outer portion near the mold constantly expelling into the liquid portion the hardening elements or

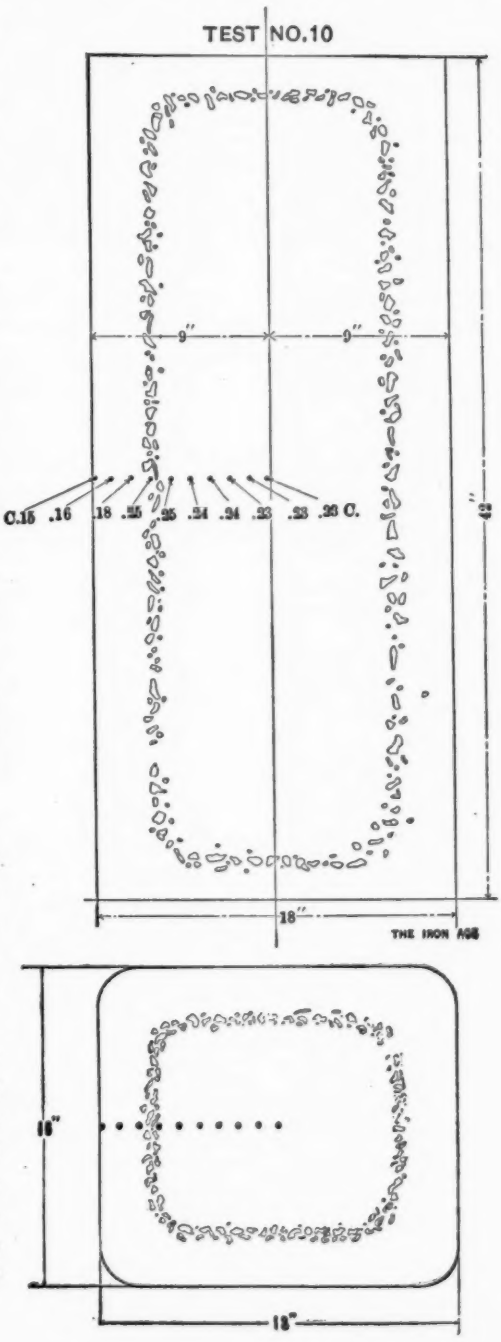


Chart 10.—Diagram of Gas Holes.—Ingot No. 2, 16 x 18 In., Cut through the Center and Drilled for Carbon Analyses.

metalloids, such as carbide of iron, etc., and these elements as the result of this steadily increasing in percentage in the liquid metal. The other is from a tendency in these metalloids to float toward the top by reason of the difference in specific gravity, these metalloids being lighter than the pure iron, and consequently they seek the top.

It will be noticed that the thinner ingots show greater difference in hardness between top and bottom near the outer edges than the thicker and heavier ones; evidently caused by the quick chilling of the metal catching the hardening elements just as they were situated, and thus preventing them from separating out and floating into the unsound discard portion at the top.

It will also be noticed that in all sizes the outer skin of the metal as it chills first against the mold, is very nearly uniform in its character, so that samples taken from all points equally distant from the outside surface will show practically the same physical and chemical properties, with the exception of the slight difference between the upper and lower portion as explained.

Steel with higher carbon, such as is used in rails, and steel treated with ferro-silicon and other similar materials such as is used for steel castings, have a different character and seem to incline more to run to a pipe in the center, owing to the different behavior of the metal in the mold in process of cooling. These steels, as stated before, I am not sufficiently familiar with to say very much about and consequently have not brought them into this article: these general characteristics may or may not apply to them.

The steel when poured is very fluid, and is in constant motion and circulation in the mold; this movement thoroughly mixing the metal and causing a continued generation of gases which pass off through the molten steel and escape, at the same time there is forming against the mold a steadily increasing coating or wall of solidified steel. As the temperature falls, however, the molten steel becomes steadily less fluid until a stage is reached where the bubbles fail to pass off through it because of its increasing thickness of consistency, and are caught just at the one point as shown. This thickening of consistency also operates to prevent the further circulation of the steel, and consequently the further generation of gases; that

portion lying inside of this zone of holes first becoming of a pasty nature and then solidifying practically all in one mass. Although these different photographs are from a number of different sizes and weights of ingots, yet they all show the same general characteristics as to the formation of the little holes or gas bubbles, all being some distance in from the outer surface of the metal.

This is aimed at as the best average condition for producing the best results we can secure in making plates, because under certain conditions if care is not exercised the bubbles will form immediately under the surface, taking the shape of honeycomb cells at right angles to the surface of the ingots; these in the after heating and rolling, will develop into a very rough or pitted surface which makes the plates unfit for the market; under other conditions the gases will concentrate in large holes in the body of the metal. Conditions of temperature of pouring and consistency of the steel, judged by experience, bring about these results, and can be very largely controlled by the steel melters.

The question would naturally arise as to the holes shown in the photos causing unsoundness in the plate, but it is quite evident that they all or nearly all close up if they are clean and free from oxides and dirt. The temperature at which the steel is heated for rolling being sufficient to bring about the practical union of the surfaces when they are pressed down into contact.

This was strikingly manifest in some of the ingots which were planed down to half thickness and subsequently rolled. They were heated with the planed side down and thus the cinder did not run into the holes, leaving them free to close up under the pressure of the rolls, the plates coming out with as clean a surface on that side as the other. If they had been heated with the holes on the top side, the cinder would have run down into them and could not have been eliminated in the rolling.

The experiments seem to show that the portion of the ingot lying inside of this zone of holes (which might be called the core of the ingot), is practically all of one character with the slight excess in the tensile strength and hardness at the top as compared with the bottom, caused by the hardening elements floating toward the top as before explained; also show that the larger the ingot and the greater the mass of metal, and the consequent greater length of time taken in solidification, the greater is the

extent of this segregation, so that though a large ingot may be rolled out and cut up into separate slabs as shown in chart Number 7 (from an ingot weighing about 18,000 lbs. and cut into eight slabs), there is still a very marked difference between the outside edges and the center of each slab, and a discard of even a large percentage from the top part of the ingot will not materially lessen this condition.

Now in the practice of rolling and shearing it is generally not practicable to secure test pieces from any portion other than the sides of the plate as rolled, and hence it is obviously necessary to so roll the ingot or slab that the sides of the plate will represent as nearly as possible the outer skin of the ingot; otherwise there would be no uniformity of results and consequently no satisfactory record of tests to report. It will be evident from this that in general mill practice, while we can report practically uniform tests from plates of the same size, rolled from the same melt of steel, yet there is metal in all these plates higher than the records show, and this, in the case of steel specified to be of high tensile strength, runs up very close to the danger line, often times seeming to us, as manufacturers, to be over the danger line: take for instance plates 1 in. or thicker, for marine boilers and specified to be 60,000 lbs. (or more) minimum tensile strength; this requires a hard steel at the best in order to secure this tensile in such thick steel, and where test pieces have to be taken from opposite diagonal corners of the plate as is now required by the United States Board of Supervising Inspectors of Steam Vessels, necessitates bringing up the softest part of the steel to the minimum requirement, so that the hard core or center which necessarily remains in the plate even after discarding a large proportion of the upper part, goes into the boiler, and is liable later on to cause cracking and trouble, if not danger.

Metal which if tested in moderate thickness, say $\frac{3}{8}$ in. would show 75,000 lbs. tensile strength would be considered too hard to use, yet the same steel is continually required to make plates of $1\frac{1}{2}$ in. thickness or thereabouts, in order to produce 60,000 lbs. to 65,000 lbs. tensile strength, and considered quite acceptable, while as a matter of fact it is much safer in the $\frac{3}{8}$ in. thickness than in the $1\frac{1}{2}$ in. thickness because of the refining effect of the rolling action.

I believe statistics will show that troubles attributable to the steel in boilers and structural work have arisen from steel being too hard, and seldom from being too soft; hardness being needed mainly to withstand abrasion or wear and in itself being of less importance for the strength of structures where a liberal factor of safety is provided for the working stress.

It has long seemed to the writer that the whole manner of figuring strength and factors of safety, etc., is wrong and that a better way would be to specify the standard desired: the steel to be accepted if it does not fall below or above by a given allowed margin, and that the strength of the structure be based on the medium tensile strength specified. The lower strength material which may be found in the plate, while it has less tensile strength, has other elements of value such as increased ductility, etc., which make up for the lower tensile strength and make this steel worthy to be used up to the same working strain in a bridge or boiler just as safely as the steel that runs up toward the upper margin. This would be a much simpler way of figuring and would result in greater satisfaction among steel makers and save a great deal of unnecessary friction and drawing of fine lines between inspectors and manufacturers as to the acceptability of the steel under present practice.

It is, of course, a common saying that the strength of a structure is the strength of the weakest part, yet it does not seem to me that this fits this case. One part may appear weaker in point of tensile strength and yet be better because of greater ductility and average value.

The rule of the Philadelphia Department of Public Safety for the construction of boilers, as adopted by the City Council in 1882, one of the earliest specifications, and prepared after careful study by prominent practical experts, provides that when iron plates show a ductility of 15 per cent. in a given length, a factor of safety of 5 shall be used in figuring the pressure allowed in the boiler, but if the plates show a ductility of 20 per cent. and stand a good bending test, they may be used with a factor of safety of 4. This would give 10,000 lbs. working strain on iron of 50,000 lbs. tensile strength with the 15 per cent. ductility, or 12,500 lbs. on iron of the same tensile strength with 20 per cent. ductility.

I believe experience in bridge construction and also experiments on steel have demonstrated that a piece showing, say 50,000 lbs. tensile strength, can work right along side of a piece 60,000 lbs. or 65,000 lbs. tensile strength and do its full share of the work: the coefficient of elasticity of steel within these ranges being practically the same; in other words, equal stresses upon the two pieces of steel will produce equal degree of elastic yielding and not strain either one of the steels or throw any undue burden upon the higher test steel, the soft steel standing up along side of it and doing its full share of the work up to the limit allowed in working strains, which is usually about one-fifth of the breaking strength of the material.

In conclusion I would venture the prediction that a fuller knowledge, on the part of engineers and users of this class of material, of the actual conditions necessarily existing in all standard made steel, and in view of the excellent results obtained as a whole heretofore from steel possessing even much greater variations than here shown, will result in less disposition to draw fine lines, and restrictions, in range of both physical and chemical tests than heretofore, and bring about a disposition to more definitely trace from effect to manifest cause in studying the elements of value in this and other classes of materials of construction.

DISCUSSION.

Mr. J. P. Snow.—I was very glad to hear the author of the paper speak in favor of low-carbon steel for general bridge work. If you will notice the printed report of Committee A (page 39), you will find an item which has been referred to the committee of the American Railway Engineering and Maintenance of Way Association for investigation. The question is as to the advisability of raising the desired ultimate strength of structural steel from 60,000 to 62,000 pounds. I don't know that it is just right to bring that in here, but as the author spoke about the advisability of low-carbon steel for general purposes, it seems that it might be discussed; and as a member of the committee on Iron and Steel Structures of the Maintenance of Way Association, I should like very much to hear an expression of opinion from the members here who are interested and who have knowledge on this subject, so that we may have the benefit of it in reporting to the Maintenance of Way Association on this question. It may not be known to all the members here that the specification for bridge material places the desired ultimate strength at 60,000 pounds, and that we allow a range of 5,000 pounds each way from that point, making the steel really from 55,000 to 65,000 pounds as possible extremes. Now as the author stated, a fairly high material is perhaps all right for thin material, but it is not all right for thick material. The general tendency of practice now is to use heavier and heavier plates and angles, and it seems to me that it is somewhat dangerous to increase the ultimate strength; not as between 60,000 and 62,000 pounds—that is all right; but if we raise the desired limit, of course we have got to raise the other limit, which would really mean an upper limit of 67,000 pounds as a possible material which we would be obliged to accept. In bridge work, this material, of course has got to be punched and sheared; and it seems to me it is dangerous to go so high, knowing that the material is to be subjected to that kind of shop usage. Mr. Snow.

Also, reverting to the discussion on ship material, I fail to see why ship material should be of a higher grade of carbon than

Mr. Snow. bridge material. It is fabricated in very much the same way; and it seems to me that the only argument for it was a word that Mr. Stratton, I think it was, dropped in the discussion, namely that if we adopt a higher steel we can use thinner material, making our ships lighter, and that it is more economical.

Now in line with the remarks of the author, it does not seem reasonable to use a higher stress on this higher carbon material. As he says, the coefficient of elasticity is practically the same for both, and it is really not the ultimate strength that we proportion for, but deformation of the material, as shown by the deflection of a bridge. We never build a bridge that is going to break down; we aim to build one that is not going to deflect too much under the load. If the bridge springs it is too light; no matter if it is strong enough to hold up ten times the load, if it springs under the strain it has got to be strengthened or be removed. So it is not the ultimate strength of the material that governs, but its action in use. As I said, I should be very glad to hear others, who understand this subject, say what they think of the proposition to raise the desired limit from 60,000 to 62,000 pounds.

Mr. Huston. MR. C. L. HUSTON.—Steel for marine boilers coming under the inspection of the United States Board of Supervising Inspectors of Steam Vessels is one of the classes of material which I had prominently in mind in preparing this paper. The conditions under which they are obliged to classify this material, under restrictions of enactments of the United States Congress seems to put them in a position that necessitates the use of very hard steel and having had difficulty with the steel cracking or showing unsatisfactory service, they have been imposing conditions to guard against this; but instead of bettering the matter, they have apparently made it worse, because they now require tests to be taken from the opposite diagonal corners—two tensile tests and two bending tests—covering in this way all four corners of the plate. These two tensile tests necessarily find the softest part of the plate and get the minimum tensile strength of the plate. This softest tensile strength is then used as the minimum showing from which to figure the pressure allowed in the boiler and because of finding the softest place for the minimum test, the whole tensile strength of the plate has to be kept up sufficiently to guard against rejection. In plates of $1\frac{9}{16}$″ thickness, which we furnish fre-

quently, it has required ingots of about 24,000 pounds weight to make them, and with such a size ingot it is manifestly very difficult to avoid considerable segregation, and consequently the central part or core of the plate necessarily goes into use, which is very much harder than it should be and involves the use of material which seems to be dangerous and inadvisable to be used in such an important place. Manufacturers and boiler makers are both inclined to the feeling that if the United States government or any other body properly qualified, specify what they want and send their inspectors to inspect it and test the steel, and the boiler maker gets it worked into a boiler successfully, then we are not responsible for it any farther. That, more than anything else, has led me to set those figures forth here, in order that people may know what exists in the interior of steel, and avoid raising the tensile strength continually, and getting hard steel in the interior, which you cannot entirely detect, and which does not seem to me to be safe to use, or at least not wise. Even in an inch and a half thickness the tensile strength in the heart of the steel, will be 75,000 pounds and consequently the material will be brittle so that, as one boilermaker said, if you try to shear off a couple of inches of a plate that is too long, with the ordinary rake of a boilermaker's shear, it will break off in chunks and fly across the shop. That is the kind of steel that is going very largely into the boilers under government inspection, where they want to get high expansion and require thick plates to carry the steam pressure. I believe you could carry the same pressure with the same thickness of steel if it had 5,000 pounds less tensile strength, because you would still have a large margin of safety on the softer steel and avoid that treacherousness and brittle nature that goes with the harder steel.

Mr. Huston.

AN EXPERIMENTAL DOUBLE-MUFFLE GAS HEATING FURNACE, FOR STUDYING THE LAWS OF THE HEAT-TREATMENT OF STEEL.

By Henry M. Howe.

General description of the furnace.—The bundle of steel bars to be heated is set vertically in the very middle of an inner vertical muffle, which in turn is set in the very middle of an outer vertical muffle, which, finally, is set in the very middle of a vertical cylindrical combustion chamber. The outer muffle is heated not only on its sides but also on its ends, and this is true of the inner muffle and also of the steel bars themselves, which are, as it were, poised in the very axis of a rather large combustion chamber, and shielded from local variations of temperature by the diffusing action of first an outer and then an inner muffle.

Turning to Figs. 1 to 4, the steel bars are shown at A, the inner muffle at D, the outer one at G. Surrounding this is the combustion chamber P, P, P, in which gas and blast, brought in through the burners L, L, L, L, generate the flame, the sole source of heat. This flame whirls about the outer muffle, and the products of its combustion escape through the outlets M, M, M (Fig. 3), to be carried off by a large ventilating hood, not shown here.

The legend to Figs. 1–3 is as follows:

A, Steel bars under test.
B, A cap to keep these bars truly centered.
D, The inner muffle.
E, A cap or plate on which it rests.
E′, A cap or plate for the outer muffle.
F, Openwork fireclay supports for the inner muffle.
G, The outer muffle.
H, Fireclay supports for the outer muffle.
J, The walls of the furnace itself.
K, Cover of the furnace.
L, The tuyeres.
M, The outlets for the products of combustion.
N, Tube carrying the leads of the thermo-junction.
O, Another tube carrying the leads of another thermo-junction.
P, The combustion chamber.

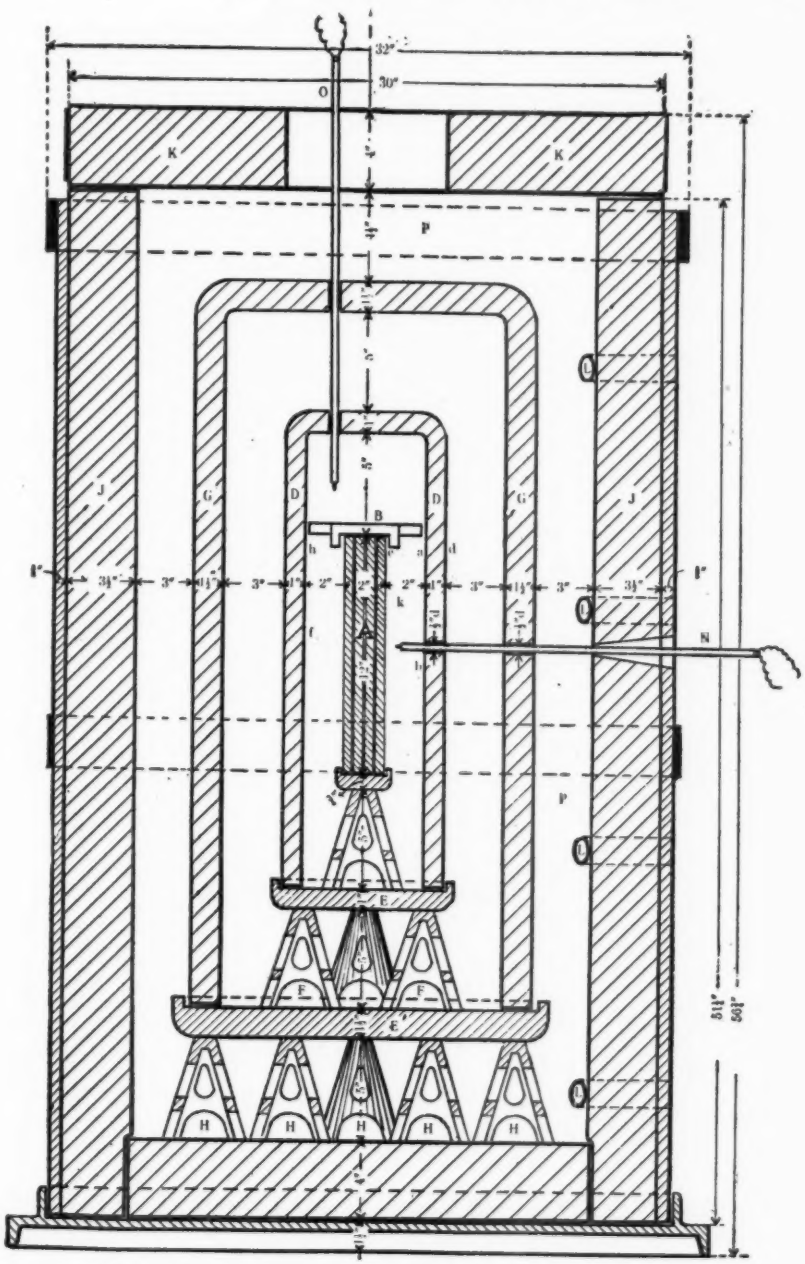


FIG. 1.—Vertical Section of Double Muffle Heating Furnace.

R, A clamp for lowering the outer muffle into place. Thick pieces of paper are set between this clamp and the muffle, and after these papers have burned away, the clamp can then readily be detached from the muffle and removed.

Object to be attained.—I designed this furnace with the object of heating steel bars with great uniformity, so as to give my officers

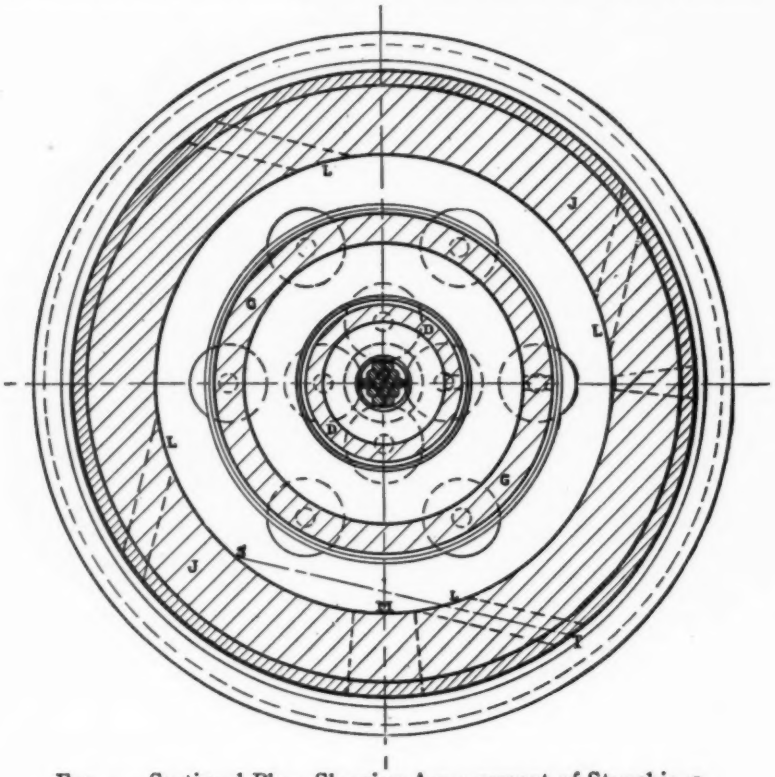


FIG. 2.—Sectional Plan, Showing Arrangement of Stanchions.

and students an efficient apparatus for studying the laws governing the heat treatment of steel. The furnace design, then, aims at great uniformity of temperature, with little regard to economy of fuel. It is solely for investigation, and unfit for industry.

Need of uniformity of temperature.—In studying these laws, we should know with great precision the temperature reached. If we are to study the effects of heat treatment on the tensile

properties, then it is desirable that our test bars should have a measured length of at least four inches, and this implies that the temperature must not only be accurately known but must be extremely uniform over the whole of this length, so that the whole of that part of the bar which is in test shall have undergone exactly the same treatment, to the end that, wherever the bar happens to

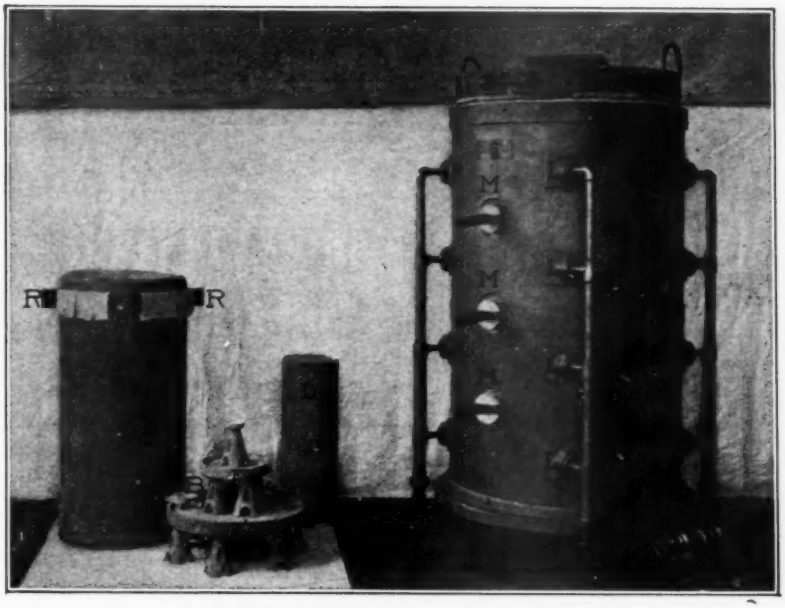


FIG. 3.—Elevation of the several parts of Double Muffle Gas Heating Furnace.
G.—Outer Muffle
E.—Inside Supports.
D.—Inner Muffle.

break, stretch, and contract, we may know that the tensile strength elongation and contraction are those strictly due to heat treatment at the temperature observed. It is indeed better, because safer, that the uniform temperature shall reach far beyond the ends of the measured length.

Difficulty in getting uniformity of temperature.—When very small test pieces are to be used, as may be done with Brinell's ball test and other tests of hardness, or with the impact testing

machines, such as those of Fremont and Guillery, then a very uniform temperature can readily be had over the whole test piece. But to create a uniform high temperature over a considerable length, such as six to ten inches, is much more difficult, because of the very different rates at which heat escapes from different parts of the exterior of most furnaces. In particular the effects of end cooling, that is to say the escape of heat through the ends of the furnace, are generally very serious, and this is true whether the axis of the furnace is vertical or horizontal.

The reason for using gas instead of electric resistance heating is the very practical one, that, at the high temperature in view, approaching 1,500° C., the platinum or other metal used for resistance breaks down so quickly that its cost is prohibitory, and, moreover that the labor of repairs and maintenance is very serious. For relatively low temperatures nothing could be more convenient than the electric resistance method. Dr. Harker's experiments lead us to hope that electric resistance furnaces may be made applicable to these high temperatures, by using solid electrolitic resistance wires of the Nernst type.*

Reasons for the muffle form.—If gas is to be used, it is indeed necessary that the bars treated should be enclosed in a muffle, so that they may be protected from the oxidizing action of the flame. Beyond this, the muffle has the very great advantage of much more uniform heating than is to be had in an open furnace, in which the flame is in the same chamber with the bars to be heated, with consequent great local variations of temperature, due to variations in the shape and volume of the flame, in its nearness to the bars treated, etc. These reasons led me to adopt the muffle form.

Reason for uniformity of temperature in muffles.—The great uniformity of temperature in muffle furnaces comes, I take it, chiefly from the fact that they heat almost wholly by radiation, with but little transfer of heat by means of either conduction or convection from the heating substance, in this case the walls, to the substance to be heated, in this case the steel bars.

If, for instance, for some special reason the spot *d* on the outside of the inner muffle, Fig. 1, works cooler than the rest, this of course tends to cool the corresponding spot *a* on the inner face of

* J. A. Harker, Proc. Royal Soc., Vol. A76, 1905, p. 235.

the muffle, and this in turn tends to make the spot *e* in the steel bars cooler than the rest of the bars. But this tendency to local cooling is strongly combated first by the tendency of the heat radiating from every other spot on the inner surface of the muffle to heat up the spot *a*, so as to compensate for the deficiency of its supply of heat from without. Heat radiates to *a* from *h*, *j*, *k*, and every other spot on the inner face of the muffle, obeying the obvious law that the transfer of heat from body to body increases with the difference in temperature between those bodies. The deficit of heat at *a* tends to cool down every spot on the face of the muffle, and conversely heat rushes from each of these other spots to heat up *a*.

The tendency to local cooling is further combated by the tendency of heat to radiate from every spot on the inner surface of the muffle more rapidly to *e* than to the hotter parts of the surface of the steel bars. Because spot *e* tends to be cooler than the rest, to it does the heat rush faster than to the rest of the surface of the bars, because of the law just quoted.

The defect of common muffles and its remedy.—In most muffles, for instance the common cupellation muffle, the uniformity of temperature is very seriously lessened by the fact that one end of the furnace, its door, not only radiates no heat into the muffle, but on the contrary is in effect a sieve through which heat rushes out very rapidly. Hence the part of the heating chamber nearest the door works much cooler than the rest. If our steel bars are set at right angles with the door, then that end of each bar which is nearest the door always remains cooler than the rest of the bar. If, on the other hand, the bars are set parallel with the door, then first those bars which are nearest the door remain cooler than those farther from it, and second that side of each bar which is nearer the door remains always considerably cooler than the opposite side.

To remedy this very serious defect I determined that my muffles should be true muffles; or, in other words, that the whole of the muffle, door and all, should be heated alike, or as nearly alike as I could arrange. This I try to effect by setting the muffles completely within a closed heating chamber, and arranging that the heat shall be supplied to the outer ends of the muffle in much the same way as to its sides.

To accomplish this I set the outer muffle far above the bottom of the combustion chamber, so that the flame can circulate freely under it and heat it well, and I leave a large space above its upper end, so that there too the flame may circulate freely and heat that end.

In the same way, I provide a large free space between each end of the inner muffle and the corresponding end of the outer one, so that the both ends of the inner muffle may be well heated by radiation, not so much from the ends as from the sides of the outer muffle. Carrying this same idea farther, I provide a large space between the ends of the steel bars to be heated and the ends of the inner muffle, so that these bars, in turn may be heated chiefly by radiation from the sides of the inner muffle, and shall depend but little on its ends. Thus, throughout this design my aim is to work by side heating, and to restrain the tendency toward end cooling.

The degree of uniformity actually attained.—As to this I am not prepared to report definitely. The extraordinary precautions which I took to secure uniformity I thought would very probably be effective. A direct set of tests by two of my students, Messrs. Edward Hess and E. M. Shipp, showed such extraordinary uniformity that I am unwilling to report them unless they are confirmed hereafter. If the temperature is really very uniform, it is easy to see how observational errors might lead to its being reported as uneven; but if the temperature is really uneven, it is very hard to understand how a series of observations over a long range of temperature should come to report it as actually very uniform. In other words, observational errors might constantly exaggerate the real variations in temperatures, and they might occasionally make the apparent variations less than the real ones; but that they should continuously and persistently cause temperatures really unlike to be reported as like, is extremely improbable. Nevertheless I prefer not to report any results at present.

Minor details.—If the tuyeres entered strictly tangentially, the flame would cut away the sides of the furnace very seriously. On this account they are directed in such a way that the flame travels a considerable distance before impinging on the walls of the furnace, as shown at S T in Fig. 2.

It was my intention that the supply of gas and blast to each tuyere could be varied independently of the others, so as to meet any tendency of the furnace to work hotter in any particular range than elsewhere. Should this prove necessary it can be arranged.

The lower part of the furnace naturally tends to work cooler

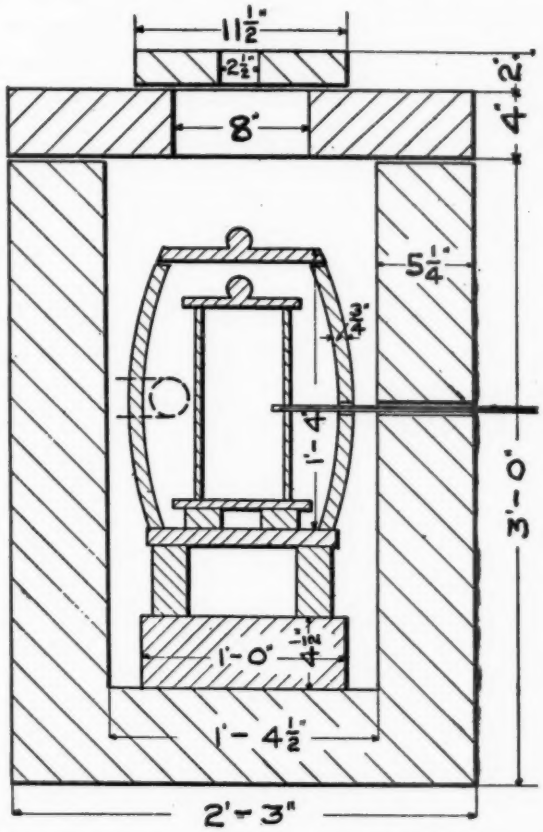


FIG. 4.—Simplified Form of Double Muffle Furnace.

than the upper part, because some support must be provided for the muffle, and these supports must necessarily both absorb heat obstruct the passage of the flame. In order to lessen this trouble these supports as shown are made hollow and open-work.

In order to make a tight joint between the muffles and their

respective caps, a ring of sand may be put on each cap, and the muffle then ground down into this sand.

The reason for choosing the vertical position was that the horizontal one leads to rapid sagging of the bars. Besides, if the bars are horizontal, the scale which falls off from them is apt to attack and destroy the walls of the muffle on which it falls. With the vertical position, any scale which falls off is caught in the cap of the muffle, and this cap is both cheaper to replace and easier to protect than the muffle itself. It is easy to protect by means of a layer of sand left upon it, which will absorb the iron scale and prevent it from eating into the cap itself.

The furnace was built by the American Gas Furnace Company, of John Street, New York City, with its characteristic enterprise. I have to thank the company most heartily for working out many of the details of the plan, and for executing it very skilfully, thus laying the cause of technical education under a further heavy load of obligation. The admirable furnaces which this company makes are of the greatest value as instruments for teaching young metallurgists.

Simplified form of furnace.—Fig. 4 shows a simplified form of this same furnace, which has been used repeatedly in my laboratory with good results. The bars under test are set with an inner muffle which consists of a large steel steam pipe, closed at each end with the cover of a graphite crucible. This inner muffle in turn is set within an outer muffle consisting of an inverted graphite crucible with its original bottom sawed off. The whole is set inside one of the American Gas Furnace Company's crucible furnaces. A fire brick should be set inside the furnace opposite each tuyere, to prevent the flame from impinging on the muffle and thus cutting it.

ON THE HEAT TREATMENT OF SOME HIGH-CARBON STEELS.

By William Campbell.

Object of the Investigation.

The object of the following research is to determine the changes which high-carbon steels undergo when submitted to heat treatment. A series of steels, varying from 0.7 to 2 per cent. carbon, were heated to temperatures ranging from 650° to 1200° C. and slowly cooled. Their mechanical properties and microstructure were worked out in detail and the changes which had occurred were contrasted.

Previous Work on the Subject.

The subject of heat treatment of steel is of such importance that a great deal of attention has been given to it. In the laboratory many experiments have been made to determine the changes which iron and steel undergo when heated to certain temperatures and either slowly or quickly cooled. The following papers apply directly to the subject and in each a particular steel was experimented with:

Fay and Badlam. Effect of Annealing upon the Physical Properties and Microstructure of a Low Carbon Steel. Technology Quarterly, 1900. The steel contained 0.07 per cent. C. and 0.32 per cent. Mn.

R. G. Morse. The Effect of Heat Treatment upon the Physical Properties and Microstructure of Medium Carbon Steel. T. A. I. M. E., 1899, 729. The steel contained 0.343 per cent. C. and 0.221 per cent. Mn.

W. Campbell. The Heat Treatment of Steel. Journal Iron and Steel Institute, II, 1903, 359. The steel contained 0.50 per cent. C. and 0.98 per cent. Mn.

G. W. Sargent. A Study of the Effect of Heat Treatment on Crucible Steel, containing one per cent. of carbon. T. A. I. M. E., 1901, 303.

In other cases a series of steels has been experimented with, and the following papers are arranged according to date:

Osmond. Méthode Générale pour l'Analyse Micrographique des Aciers au Carbone: Bull. de la Soc. d'Encouragement, 1895, x 476.

Osmond and Stead. Microscopic Analysis of Metals (Lippincott Co.). Deals with a series of four steels containing 0.02, 0.14, 0.45 and 1.24 per cent. carbon respectively. The transformations of structure which take place within the range of the critical points are studied.

Sauveur. The Microstructure of Steel and the Current Theories of Hardening. Trans. A. I. M. E., 1896, 863. Five steels containing 0.09, 0.34, 0.80, 1.20 and 2.50 per cent. carbon respectively were slowly cooled and the changes described. Hardening is discussed.

Stead. The Crystalline Structure of Iron and Steel. Journal Iron and Steel Institute, 1898, I, 145. Deals with a series of six steels, running 0.01, 0.11, 0.21, 0.47, 0.86 and 1.14 per cent. carbon. The change of size of grain with heat treatment and the relation of the critical points are worked out.

Wahlberg. Brinell's Method of Determining Hardness and other Properties of Iron and Steel. Journal Iron and Steel Institute, 1901, II, 234. The carbon of the steels used ranges from 0.09 to 1.17, and the temperatures of annealing vary from 350° to 1200° C.

Campion.

Some Experiments on the Methods of Annealing Steel. Journal W. of Scotland I. and S. Institute, 1901 (Metallographist IV, 53); and

The Heat Treatment of Steel under Conditions of Steel Works Practice. Journal Iron and Steel Institute, 1903, I, 378. Deals with steels containing 0.2 to 0.65 per cent carbon.

J. O. Arnold. The Properties of Steel Castings. Journal Iron and Steel Institute, 1901, I, 175. Illustrates the structural changes in annealing sixteen or more castings whose carbon runs from 0.06 to 1.75.

Arnold and McWilliam. The Thermal Transformations of Carbon Steels. Journal Iron and Steel Institute, 1905, II, 27. Shows the changes in three steels 0.21, 0.89 and 1.78 per cent. carbon and their relation to the critical points.

The Sixth Report of the Alloys Research Committee. Institution of Mechanical Engineers, London, 1904. A set of eight steels whose carbon contents were 0.13, 0.18, 0.254, 0.468, 0.722, 0.871, 0.947 and 1.306 per cent. were annealed for ½ hour at 620°, 720°, 800°, 900° and 1100° C. Their mechanical properties and microstructure were examined. A second series of experiments consisted in annealing at the above temperatures for 12 hours. The subject of hardening is also taken up.

The list of papers given is merely a selection chosen for reference. The above work shows that the effects of heat treatment upon steel are dependent upon the critical points and that the relation of the microstructure to the mechanical properties is very

intimate. Looking over the literature, however, it will be seen that most of it relates to steel with less than 1 per cent. carbon and that steels consisting of cementite and pearlite have not received so much attention as those consisting of ferrite and pearlite. It seemed fitting, therefore, to undertake research work on steel high in carbon.

MATERIAL USED.

Crucible Steel.—A series of six steels rolled in the regular way into bars $\frac{5}{16}$ inch square, was presented by the Carpenter Steel Company, and thanks are due to Mr. W. B. Kunhardt.

The analyses given in the following table show the manganese to be low, whilst the phosphorus and sulphur are in all cases less than 0.02 per cent.:

ANALYSES OF STEELS.

Number.	C.	Mn.	P.	Si.	S.
1	2.04	0.28	0.014	....	0.014
2	1.94	0.20	0.009	0.17	0.013
3	1.72	0.075	0.013	0.20	0 018
4	1.61	0.19	0.013	0.19	0.013
5	1.04	0.12	0.012	....	0.017
6	0.70	0.068	0.012	0.141	0.019

DETERMINATION OF CRITICAL POINTS.

The critical points were determined with a Le Chatlier pyrometer, a platinum and platinum-iridium thermocouple, using the telescope-scale-galvanometer method. The scale length was 50 cm. divided into millimeters, and the deflection of the galvanometer was such that each scale division corresponded to 2° C. Half scale divisions could be read with ease.

The thermocouple was standardized by the freezing points of copper, aluminum, antimony, zinc and lead and the boiling point of sulphur. The steels were heated in a small Fletcher furnace, in a crucible packed with asbestos. No retardations above A_1 were found. The following table gives two readings for each steel:

Steel Number.	Per Cent. Carbon.	Ac_1.		Ar_1.	
1	2.04	737° C.	736° C.	708° C.	707° C.
2	1.94	731	734	704	705
3	1.72	730	740	710	707
4	1.61	732	736	707	708
5	1.04	730	731	697	696
6	0.70	730	736	702	701

The fact that the two readings for Ar_1 agree to 1° C. and that those for Ac_1 are more widely apart is due in part to the difference in the rates of heating and cooling. The furnace cooled from 1000° C. to just below 700° C. in fifteen minutes, but in heating the time was much shorter. The average temperature for Ac_1 is 733° C. and for Ar_1 704° C.

The critical points Ac_{2-3} and Ar_{2-3} were not found, the evolution of heat being too small to cause a marked break in the curve for this method of work.

METHOD OF HEAT TREATMENT.

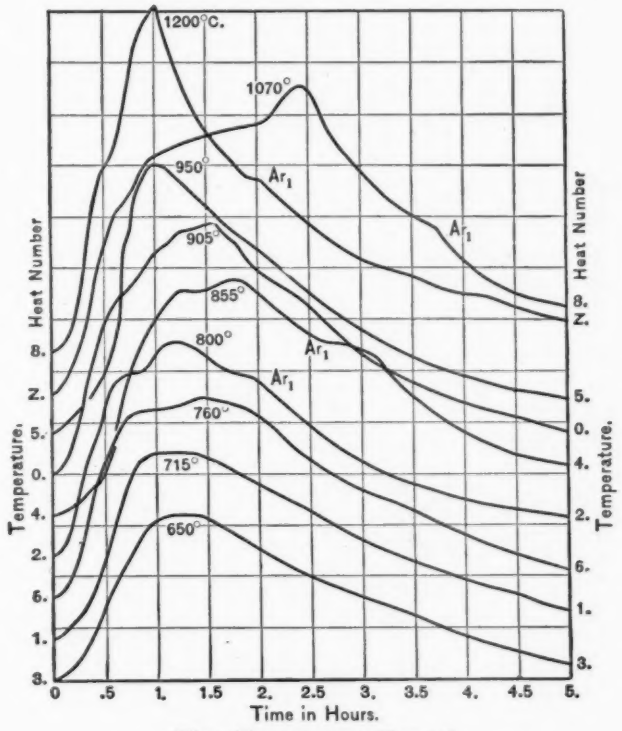
The bars were cut up into lengths of 12 inches and heated in batches of six, one of each steel. The heats were made in a horizontal cylindrical gas forge 21 inches long, 7 inches internal diameter, with two rows of five burners set tangentially.

The six bars were packed in an iron tube 15 in. x 2 in. diameter, with a porcelain thermocouple tube in their midst. The iron tube was packed with lime and had asbestos plugs at each end. The whole was placed in the axis of a larger iron pipe 18 in. x $3\frac{1}{2}$ in. diameter with cast-iron covers for each end, fixed inside of the forge. This outer iron pipe acted as a muffle and thus the bars were heated by radiation. This method of heating by radiation is very simple, is easy to regulate and gives very uniform temperatures throughout the length of the inner tube.

The furnace was charged cold and the heat was so regulated that the bars reached the maximum temperature aimed at in about one hour. At this rate of heating it seems almost certain that it would only take a few minutes for $\frac{5}{16}$ in. square bars to reach a uniform temperature. Therefore, as soon as the maximum temperature was steady, say in five minutes or more, the gas and blast

were turned off and the whole allowed to cool slowly. In about 4½ hours after starting the furnace was cold enough to open.

An exact record of heating and cooling of each lot of steel was kept by a Le Chatelier pyrometer, and this time-temperature record has been plotted as shown. The hot junction of the thermo-couple was situated in the center of the axis of each bundle of steel, and so the record given is for that point. The curves have



Time-Temperature Record.

all been plotted on one sheet to economize space. In order to keep them distinct the zero for temperature for each steel is placed $\frac{8}{10}$ of a division above that of the next lower heat. With the exception of heat Z to 1070° C. the maxima are fairly regular. The irregularity of this heat was due to a fall in pressure of the blast. The evolution of heat due to Ar_1 or the recalescence point is marked in most of the curves.

SUMMARY OF HEAT TREATMENT.

Heat No.	Heated to
3	650° C
1	715
6	760
2	800
4	855
0	905
5	950
Z	1070
8	1200

The above temperatures were very close to those aimed at, viz: 650°, 710°, 750°, 800°, 850°, 900°, 1050° and 1200° C. The reason for chosing these temperatures was that we might have one heat below the critical range, one at Ar_1 which was found to be 710–700° C., one just above the point where Ac_1 is complete (730–740° C.,) and five others lying between this point and 1200° C., where we know overheating occurs. In this way one heat is made to a maximum where pearlite is still stable, another to a maximum where pearlite forms *on cooling* (Ar_1), thus completing any changes which may have been held back by the comparatively rapid cooling of $\frac{5}{16}$-inch bars at the rolls. A third is made to that region where the change from pearlite into solid solution, or austenite, is complete, i. e. the end of Ac_1, whilst by heating to temperatures above this we pass through the ranges A_{2-3} or the solution of the cementite in the solid solution Austenite.*

MECHANICAL TESTS.

The tests were made on a Riehlé testing machine in the Testing Laboratory, Columbia University, which Professor Woolson kindly placed at my disposal.

The test-bars were cleaned on an emery wheel before pulling. The elastic limit was determined by drop of the beam and the elongation measured on 2 inches. To act as a standard of comparison two bars of each steel were pulled as received and these are numbered A and X respectively. The figures thus obtained are tabulated in Tables A to F and these tables have been plotted in figures A to F.

* Rooseboom: Eisen und Stahl von Standpunkt der Phasenlehre. Zeits. f. Phys. Chem. 34 (1900), 437. Howe: Iron, Steel and Other Alloys. P. 177 *et seq.*

TABLE A.—Steel No. 1. C. = 2.04. Mn. = 0.28.

Heat No.	Heated to	Elastic Limit. lbs. per sq. in.	Maximum Load. lbs. per sq. in.	Elongation in 2 inches.	Reduction of Area per cent.	Fracture and Microstructure.
A	As rolled	101,800	144,600	4.5	3.5	Fracture fine. Fig. 7. Microstructure—Fe_3C as fine irregular network and as coarse patches.
X	As rolled	104,200	144,000	4.0	3.0	
3	650° C.	84,600	115,400	6.0	6.5	Broke in grips. A second pull gave M. L. = 123,400 lbs. Fe_3C becoming globular. Fig. 19.
1	715°	83,900	114,500	7.0	6.6	
6	760°	57,700	98,800	11.5	16.2	Fracture very fine. Fe_3C globular.
2	800°	57,800	95,650	12.5	19.6	Broke near grips. A second pull gave M. L. = 99,000 lbs. Fracture finest. Fig. 8.
4	855°	55,500	93,800	12.0	13.2	
0	905°	55.350	95,250	11.5	12.6	
5	950°	49,350	95,200	6.0	5.8	Fracture coarser than original. Fig. 19. Microstructure. Fig. 21.
Z	1070°	49,600	99,000	4.5	2.7	Fracture very coarse. Fig. 10. Fe_3C coarse and globular. Fig. 23.
8	1200°	56,000	57,400	1.0	0.4	Broke in grips. A second pull gave M. L. = 64,400 lbs. Fe_3C as very coarse irregular network. Graphite in center. Figs. 25 and 24.

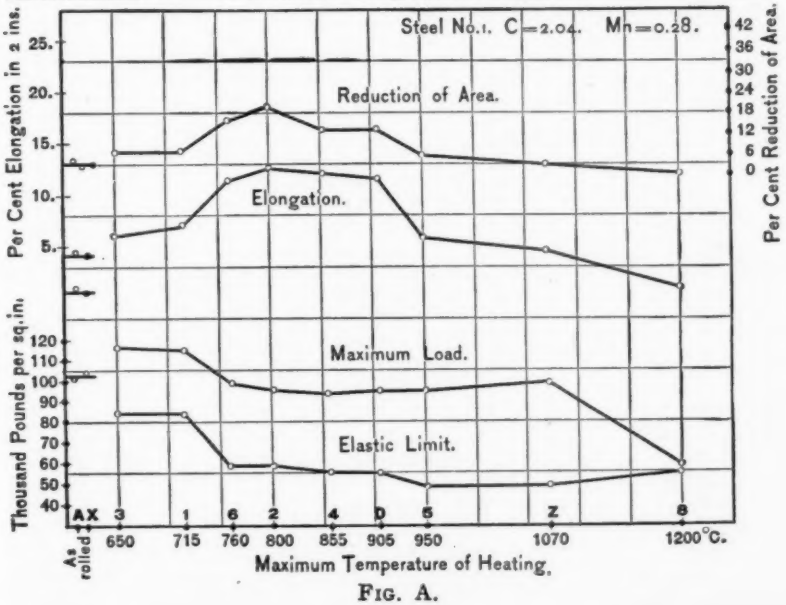

Steel No. 1. C = 2.04. Mn = 0.28.
Per Cent Elongation in 2 ins.
Per Cent Reduction of Area.
Reduction of Area.
Elongation.
Thousand Pounds per sq. in.
Maximum Load.
Elastic Limit.
AX 3 1 6 2 4 0 5 Z 8
As rolled 650 715 760 800 855 905 950 1070 1200°C.
Maximum Temperature of Heating.

FIG. A.

TABLE B.—Steel No. 2. C. = 1.94. Mn. = 0.20.

Heat No.	Heated to	Elastic Limit.	Maximum Load.	Elongation in 2 inches.	Reduction of Area per cent.	Fracture and Microstructure.
		lbs. per sq. in.	lbs. per sq. in.			
A	As rolled	91,000	146,500	6.0	6.5	Fracture similar to steel No. 1. Microstructure—Fe_3C as fine irregular network with a few coarse patches. Fig. 28.
X	As rolled	91,500	146,300	6.5	6.0	
3	650° C.	72,600	115,200	8.0	8.9	Broke in grips. A second pull gave M. L. = 120,600 lbs.
1	715°	68,650	104,100	9.5	12.0	
6	760°	50,500	95,000	15.0	18.8	Fracture finest. Fe_3C becomes globular.
2	800°	51,000	92,000	17.0	15.0	
4	855°	49,450	89,000	12.5	12.1	
0	905°	49,800	95,350	7.0	9.5	Broke in grips. A second pull gave M.L. = 99,800.
5	950°	41,750	91,800	9.5	12.0	Fracture coarse at edge. Microstructure. Fig. 30.
Z	1070°	47,000	97,000	8.5	7.6	Fracture very coarse. Fe_3C in coarse globules. Fig. 31. Graphite in center. Fig. 32.
8	1200°	.....	61,350	2.0	1.4	Very much graphite. Figs. 34 and 35.

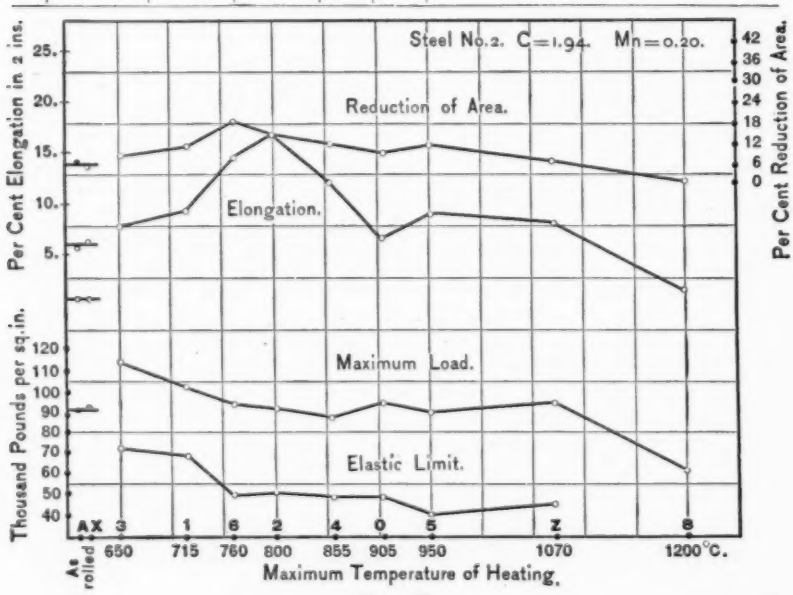


FIG. B.

TABLE C.—Steel No. 3. C. = 1.72. Mn. = 0.075.

Heat No.	Heated to	Elastic Limit.	Maximum Load.	Elongation in 2 inches.	Reduction of Area per cent.	Fracture and Microstructure.
		lbs. per sq. in.	lbs. per sq. in.			
A	As rolled	98,700	152,800	6.5	5.2	Fracture similar to steel No. 2. Microstructure—Fe_3C as fine regular network. Fig. 37.
X	As rolled	97,500	154,000	8.0	8.7	
3	650° C.	78,300	126,000	8.0	7.3	Broke in grips. A second pull gave M. L. = 129,000 lbs. Microstructure. Fig. 38.
1	715°	75,700	114,100	11.5	18.8	Fracture very fine. Fe_3C network breaking down.
6	760°	50,500	100,300	16.5	20.5	Fracture very fine.
2	800°	48,750	98,000	10.0	10.3	Broke in grips. A second pull gave M. L. = 105,400 lbs.
4	855°	47,900	94,000	13.5	12.0	Fe_3C is now globular. Fig. 39.
0	905°	48,600	94,350	11.0	9.6	
5	950°	45,200	95,000	7.5	6.3	Microstructure. Fig. 40.
Z	1070°	43,100	92,350	6.0	4.3	Fracture very coarse. Graphite formed.
8	1200°	50.600	65,300	2.0	1.0	Broke in grips. A second pull gave M. L. = 79,200 lbs. Fe_3C as coarse network. No graphite. Figs. 41 and 42.

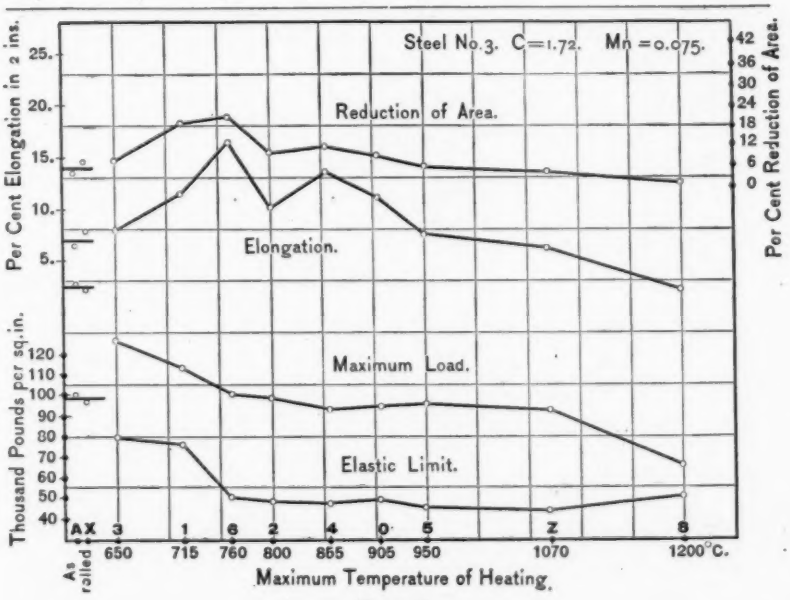


FIG. C.

TABLE D.—Steel No. 4. C. = 1.61. Mn. = 0.19.

Heat No.	Heated to	Elastic Limit.	Maximum Load.	Elongation in 2 inches.	Reduction of Area per cent.	Fracture and Microstructure.
		lbs. per sq. in.	lbs. per sq. in.			
A	As rolled	105,200	162,200	7.0	8.2	Fracture finer than steel No. 3. Fig. 12.
X	As rolled	105,200	153,200	6.0	9.1	Microstructure—like steel No. 3. Cell walls of Fe_3C thinner.
3	650° C.	85,300	128,100	....	8.3	Broke in grips. A second pull gave M. L. = 129,100 lbs.
1	715°	81,300	117,000	14.5	21.5	
6	760°	52,300	98,650	0.0	34.0	Fracture finest. Fig. 13.
2	800°	53,350	97,700	18.5	19.1	
4	855°	51,350	95,000	15.0	14.2	Fe_3C now globular. Fig. 36.
0	905°	51,350	97,350	11.5	9.4	
5	950°	48,500	96,350	7.5	6.8	
Z	1070°	51,400	94,400	3.5	2.6	Fracture very coarse. Graphite formed. Figs. 43 to 46.
8	1200°	.....	69,800	3.0	1.9	Broke in grips. A second pull gave M. L. = 80,800 lbs. Fracture. Fig. 14. Fe_3C as coarse network. No graphite. Figs. 47 and 48.

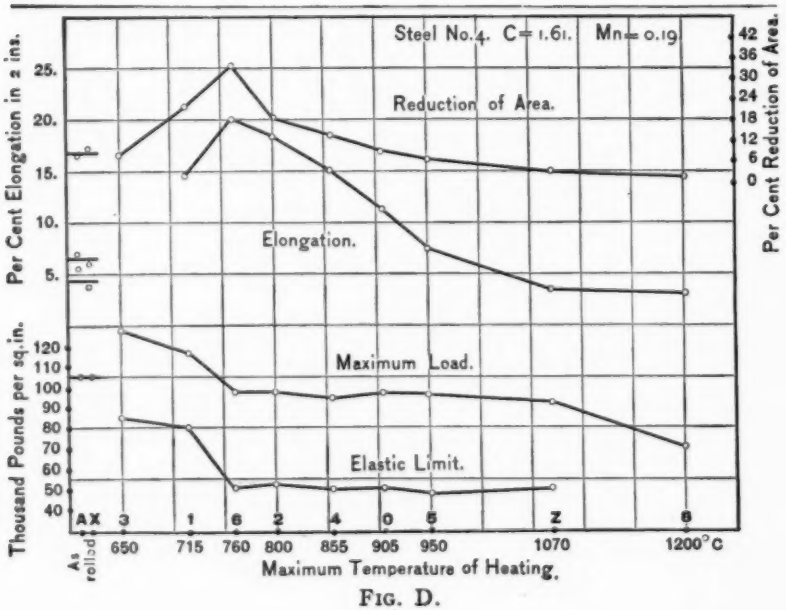


FIG. D.

TABLE E.—Steel No. 5. C. = 1.04. Mn. = 0.12.

Heat No.	Heated to	Elastic Limit.	Maximum Load.	Elongation in 2 inches	Reduction of Area per cent.	Fracture and Microstructure.
		lbs. per sq. in.	lbs. per sq. in.			
A	As rolled	75,800	140,600	13.5	22.7	Fracture shows dull center.
X	As rolled	75,800	141,600	12.0	21.8	Microstructure—all pearlite.
3	650° C.	57,700	105,400	18.0	36.2	Broke in grips. A second pull gave M. L. = 107,200 lbs.
1	715°	55,200	97,800	22.0	41.5	Fracture finest.
6	760°	44,850	86,800	26.5	36.6	Pearlite grain finest.
2	800°	46,600	96,600	19.0	21.0	
4	855°	47,200	111,800	13.0	11.3	Fracture very coarse.
0	905°	50,600	115,900	13.0	8.8	
5	950°	46,800	111,500	10.5	10.9	
Z	1070°	56,500	106,100	11.0	10.6	
8	1200°	89,600	112,600	11.5	10.7	

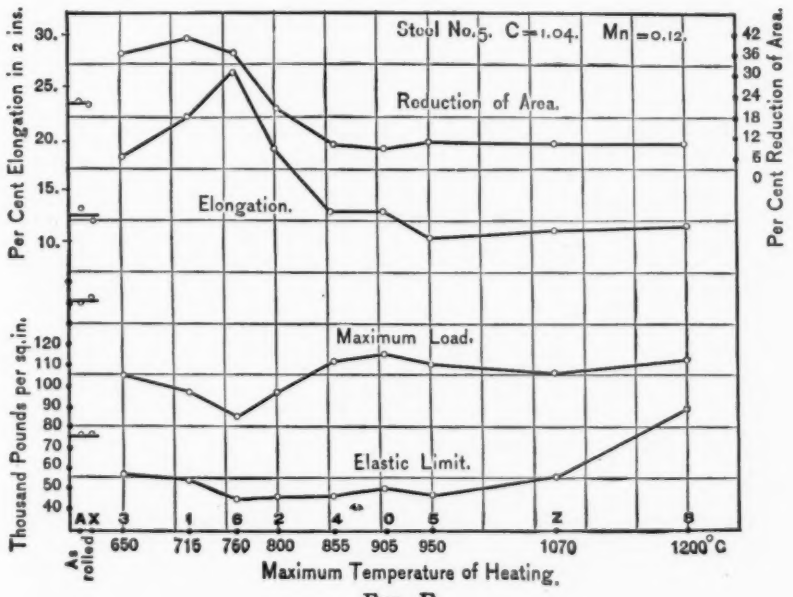


FIG. E.

TABLE F.—Steel No. 6. C. = 0.70. Mn. = 0.068.

Heat No.	Heated to	Elastic Limit.	Maximum Load.	Elongation in 2 inches.	Reduction of Area per cent.	Fracture and Microstructure.
		lbs. per sq. in.	lbs. per sq. in.			
A	As rolled	65,300	117,400	17.0	27.3	Fracture similar to steel No. 5. Fig. 15.
X	As rolled	64,200	116,600	17.0	27.0	Microstructure—all pearlite.
3	650° C.	53,250	95,200	23.0	33.9	Broke in grips. A second pull gave M. L. = 96,600 lbs.
1	715°	49,700	88,700	27.5	45.2	Fracture finest. Fig. 16.
6	760°	40,200	85,600	27.0	38.7	Fracture. Fig. 17.
2	800°	42,150	94,300	19.0	20.9	Fracture very coarse.
4	855°	42,100	91,350	18.5	20.7	
0	905°	41,400	90,300	18.0	21.8	
5	950°	39,700	90,500	16.5	20.5	Fracture. Fig. 18.
Z	1070°	57,350	89,500	18.0	17.9	Broke outside punch marks. A second pull gave M. L. = 90,100 lbs.
8	1200°	58,500	90,000	16.0	16.8	

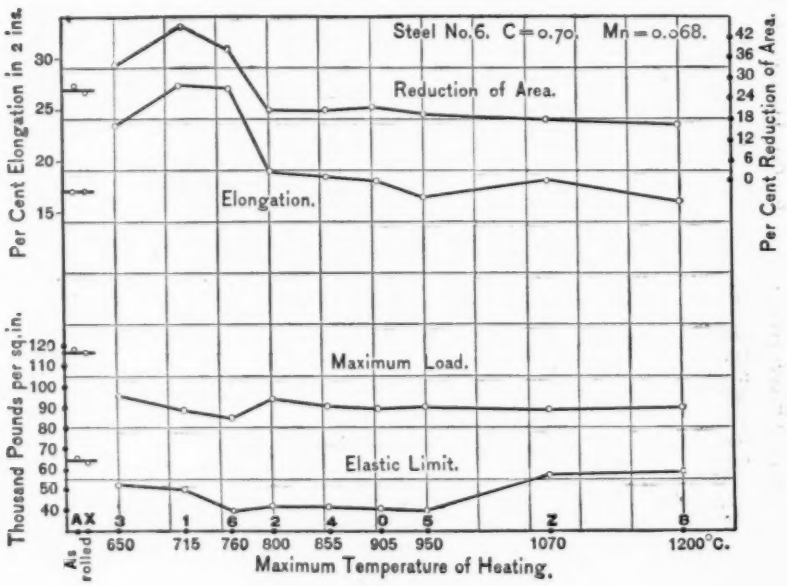

Steel No. 6. C = 0.70. Mn = 0.068.
Reduction of Area.
Elongation.
Maximum Load.
Elastic Limit.
Per Cent Elongation in 2 ins.
Per Cent Reduction of Area.
Thousand Pounds per sq. in.
AX 3 1 6 2 4 0 5 Z 8
As rolled 650 715 760 800 855 905 950 1070 1200°C.
Maximum Temperature of Heating.

FIG. F.

DISCUSSION OF RESULTS.

Steel No. 1. *C.* = 2.04. *Mn.* = 0.28.

The figures obtained for the elastic limit, maximum load, elongation and reduction of area, are given in Table A and plotted in Fig. A. As rolled this steel has a M. L. of 144,000 pounds per square inch with an elongation of 4 per cent. and a reduction of 3 per cent. Heating to 650° and 715° C. brings down the M. L. some 30,000 pounds and raises the elongation and reduction to between 6 and 7 per cent. This heating to points below the critical temperatures Ac_1 has brought about well marked changes and, therefore, according to some authorities, the original steel must have been either cold rolled or passed through the critical range Ar_1 so quickly that the change was not complete. The change, however, is mainly due to segregation.

Heat No 6. to 760° C. brings a drop in the M. L. and E. L. with a strong rise in ductility. The fracture is very fine. Heat No. 2 to 800° C. makes but little change in the M. L. and E. L., but brings the ductility up to a maximum. The fracture is the finest of the series. Further heating has but little effect on the strength of the steel till we pass heat Z 1070° and in heat 8 at 1200° C. the treatment has reduced the M. L. to 57,000 pounds per square inch. The ductility also shows a gradual falling off, until in heat 8 we have it reduced to a minimum.

The explanation of the above changes is simple when we examine the fractures and microstructure. Fig. 1 shows the fractures of each heat ranging from A to 8 and heat 2 gives the finest as is seen when Fig. 8 is contrasted with Figs. 7 and 9, the fractures as rolled and after heating to 950° C., heat 5. Another marked change is seen in heat Z (to 1070° C.), shown in Fig. 10, while the fracture of heat 8 (to 1200° C.), shown in Fig. 11 is the coarsest of all.

The microstructure shows similar changes. Heating to 760° C. while refining the pearlite does not quite refine the cementite. Heating to 800° C. on the other hand refines the whole. Above this point the cementite becomes more globular and the pearlite coarser, till at 1070° C. we find the cementite breaking down and graphite forming. Finally, heating to 1200° C., in addition to producing graphite, yields an extremely coarse grain (Figs. 24 and 25) and in consequence the ductility falls to a minimum.

Steel No. 2. C. = 1.94. Mn. = 0.20.

The results of the mechanical tests for this steel are given in Table B and plotted in Fig. B. If we contrast these results with those obtained for steel No. 1 we see that they are practically the same, except that heat 6 to 760° C. caused refining. The elongation of heat 0 to 905° C. is low because fracture occurred in the grips and the curve undoubtedly ought to be smooth from heat 2 to heat Z.

Examining the curves, we see that the M. L. and E. L. fall gradually to heat 6 (760°) after which there is very little change until at heat 8 we have extreme overheating. The ductility on the other hand rises to a maximum between heats 6 and 2, and then gradually falls to a minumum at 1200° C., heat 8.

The fractures of the test-pieces are shown in Fig. 2 and range from A to 2 below and 4 to 8 above. Heat 6 gave the finest but heat 2 was very little coarser. Heat 5 gives a fracture with black edges due to the separation of graphite as shown in Fig. 29. Finally in heat Z the separation of graphite is extreme and shows both in fracture and in microstructure, Figs. 32 and 34.

Steel No. 3. C. = 1.72. Mn. = 0.075.

Table C and Fig. C give the results obtained for this steel. The curves for M. L. and E. L. are very similar to those for steel No. 2. The bar for heat 2 to 800° C. broke in the grips, giving low readings for elongation and reduction of area. Taking this into consideration the curves showing ductility are the same as those of steel No. 2.

Here also we have refining at 760° C. with overheating at 1070° C. This is also shown by the assembled fractures in Fig. 3 and by the microstructure, Figs. 41 and 42. It is to be noted that, whereas much graphite is found in heat Z to 1070° C. none occurs in heat 8 to 1200° C.

Steel No. 4. C. = 1.61. Mn. = 0.19.

The mechanical tests for this steel are tabulated in Table D and plotted in Fig. D. In the rolled condition this steel shows a greater maximum load and elastic limit than the others of the suite. As before the M. L. and E. L. are reduced by heating to 650° and

715° C. This falling off reaches a minimum in heat 6, to 760° C. and we have a fairly constant strength between 90,000 and 100,000 pounds per square inch till at heat 8 (1200° C.) it falls below 70,000 pounds. These curves are similar to those of steel No. 3.

The curves for reduction of area and elongation show a maximum at heat 6 (760° C.) followed by a steady decline till at 1070° overheating is very strong. The fractures are seen in Fig. 4 and marked changes are shown at heats 6 and Z. Fig. 12 shows the fracture of the steel as rolled, Fig. 13 that of heat 6 (760° C.) the best refining, whilst in Fig. 14 we have the very much overheated bar 8 (to 1200° C.). Like steel 3 the refining occurs at 760° C. above which we have the cementite becoming coarser. Graphite forms at 1070° C., Figs. 43–46, but heat 8 to 1200° C. produces none. The structure obtained is shown in Figs. 47 and 48, high and low magnification.

Steel No. 5. $C. = 1.04$. $Mn. = 0.12$.

Table E gives the figures for this steel and Fig. E the curves. For steels Nos 1 to 4 the curves for M. L. and E. L. follow each other and by plotting each four curves in one sheet, it is at once seen that they all follow the same law and undergo the same changes. Steel No 5, however, does not behave the same as Nos. 1 to 4. As before we have a fall in strength to heat 6 (760° C.), but instead of remaining constant it again rises and reaches a maximum in heat 0 at 905° C., whilst in the case of heat 8 (1200° C.) the strength goes up again.

The ductility reaches a maximum as before at heat 6 (760° C.) which is followed by a rapid fall. Overheating takes place at heat 4 or 855° C. This is shown by the fractures, Fig. 5, where bar 4 is extremely coarse-grained. The microstructure consists wholly of pearlite.

The difference then between steels 1 to 4 and steel 5 lies in the fact that the former consist of pearlite and cementite, the latter of pearlite alone. The difference in their behavior under heat treatment must be due in some way to the behavior of the cementite. Morse* in his examination of a steel containing 0.34 per cent. carbon gives a curve for M. L. which shows a fall to say 750° C. fol-

* Trans. Am. Inst. Mining E., 1899. 729.

lowed by a rise to 900° C. then a fall at 1100° C. with a sharp rise at 1300° C. Campbell* in a steel with 0.5 per cent. C. and 0.98 per cent. Mn. found a similar series of curves. Fay and Badlam† for a 0.07 per cent. C. steel found the rise in M. L. at 1125 while Ball‡ with 0.12 per cent. C. steel found a critical point at 1300° C., all of which results seem to indicate a change of state in this region of extreme overheating, or, according to Osmond, the existence of the δ modification in addition to the α, β and γ forms. In the case of steels Nos. 1 to 4 this change is more than balanced by the breaking down of the cementite into graphite at 1070° C. or by the formation of the coarse network of cementite in bars heated to 1200° C. as in Fig. 48.

The heating to just above the critical point Ac_1 produces the maximum ductility at the expense of the tensile strength, while heating to points above Ac_1 to say, 900° C. increases the strength at the expense of the ductility.

Steel No. 6. C. = 0.70. Mn. = 0.068.

The mechanical properties are given in Table F and Fig. F. As before, heating to the critical point Ac_1 raises the ductility at the expense of the M. L. and E. L., which show a minimum in heat 6 (760° C.). The ductility, however, is greater in the case of heat 1 (715°C.), and shows a marked drop in bar 2, showing that overheating occurred at so low a temperature as 800° C. This is clearly shown when the fractures are examined as in Fig. 6, where there is a marked change between bars 6 and 2. These changes can also be seen in Figs. 15 to 18.

The microstructure is similar to that of steel No. 5 and consists of pearlite alone, and it seems remarkable that this steel should overheat at a lower temperature.

SUMMARY OF RESULTS OF MECHANICAL TESTS.

The steels can best be treated in two groups, i. e. those consisting of pearlite and cementite, or Nos. 1 to 4, and those consisting of pearlite alone, Nos. 5 and 6.

*Journal I. and S. Inst., 1903, II.

† Tech. Quarterly, 1900.

‡ Journal I. and S. Inst., 1890, I, 85, 1891, I, 103.

Maximum Load.—Of the first four steels No. 4 with 1.61 per cent. C. is the strongest with 160,000 pounds per square inch, No. 1 with 2.04 per cent. C. the weakest with 144,000 pounds per square inch. Heating to 650° C. reduces this about 30,000 pounds. Heating to just above the critical point Ac_1 (760° C.) brings down the M. L. to approximately the same point between 95,000 and 100,000 pounds per square inch. Heating to higher temperatures has but little further effect until with heat 8 (1200° C.) the M. L. drops suddenly to between 70,000 and 58,000 pounds and, as before, No. 4 is the strongest and No. 1 the weakest.

Of the last two steels No. 5 with 1.04 per cent. carbon is stronger with 140,000 pounds per square inch, No. 6 is weaker with 0.70 per cent C. and 117,000 pounds per square inch.

Heating to just above the critical point (760° C.) brings down the M. L. to 86,000 pounds. Heating to higher temperatures improves No. 6 but slightly, and the 1200° C. heat gives M. L. 90,000 pounds. In the case of No. 5, however, heating to higher temperatures makes a great increase, the 905° C. heat giving a maximum at 116,000 pounds per square inch, and the 1200° C. heat giving 112,000 pounds.

Elastic Limit.—The curves are similar in shape to those of M. L. Heating to 650° C. causes a fall of about 20,000 pounds per square inch.

Heating to above critical point (760° C.) reduces the E. L. to a point between 50,000 and 58,000 pounds per square inch for the first four steels and to 45,000 and 40,000 pounds for steels 5 and 6. In the 950° C. heat the E. L. for all lies between 40,000 and 50,000 pounds per square inch.

Heating to higher temperatures causes a slight improvement in the case of steels 1 to 4, which is more marked in steels 5 and 6.

Reduction of Area.—In the curves for the first four steels we have a maximum for the heat just above the critical point (760° C.) followed by a rapid fall to 11–14 per cent. for the 850° C. heat, and then a uniform decline to less than 2 per cent. for the 1200° C. heat.

For steels 5 and 6 the maximum (over 40 per cent.) occurs with heat 1 (715° C.) followed by a drop to 21 per cent. for the 800° C. heat.

Elongation.—The maximum point varies, being at 715° C. for steel 6, 760° C. for steels 5, 4 and 3, and at 800° C. for steels 2 and 1.

This follows when we consider that the point $Ac_{2\text{-}3}$ or the solution point of cementite increases with carbon content. In other words, the more cementite present the higher the refining temperature, just as the lower the carbon below 0.8 or the more ferrite present the higher the refining temperature.*

Heating to higher temperatures causes a falling off. In the case of steels 1 to 4 this is uniform and reaches 3 per cent. or less with the 1200° C. heat. In the case of steels 5 and 6 a minimum is reached with the 950° C. heat.

EXAMINATION OF FRACTURES.

In Figs. 1 to 6 we have the fractures of the test-pieces of steels 1 to 6. Starting at the lower right hand corner we have the two fractures of the steel as rolled marked A. Next comes the pair from the steel heated to 650° C. marked by the heat number 3 and so on.

In Fig. 1, fractures for steel 1, C. =2.04, the finest fracture is given by heat 2 (800° C.). Heating to 950° C. (5) does not give a very coarse fracture but when the heat reaches 1070° C. (Z) we have a coarse dark fracture. These changes can readily be followed in examining Figs. 7, 8, 9 and 10; each magnified 6 diameters. Fig. 11 shows the fracture of the bar heated to 1200° C. It is coarsely crystalline with a columnar border $\frac{1}{3}$ of radius.

In Fig. 2, fractures for steel 2. C. = 1.94, the finest fracture occurs in heat 6 (760° C.). Heat 4 shows a thin crystalline border, which becomes thicker in the higher heats and finally in heat 5 (950° C.) shows black streaks near the edge, due to separation of graphite. Heat Z (1070° C.) again shows a marked change, the fracture having a coarse crystalline border and a black center, due to graphite. In heat 8 (1200° C.) the columnar border is $\frac{1}{3}$ radius.

Fig. 3 shows the fractures for steel No. 3. C. = 1.72 per cent. Fractures 1 (715° C.) and 6 (760° C.) are very fine. Beyond this they become gradually coarser and the crystalline border begins to show. Heat Z (1070° C.) very coarse with strong columnar border which is even more marked in heat 8 (1200° C.) but of lighter color.

*Change of Structure in the Solid State. Journal Franklin Institute, Sept., 1904.

Fig. 4 shows the fractures for steel No. 4. C. = 1.61 per cent. The fracture as rolled, Fig. 12, is finer and darker than steels 1–3. Heat 6 (760° C.), Fig. 13, shows the finest and darkest fracture. Beyond this there is a sharp change of color, the grain becomes coarser and a crystalline border begins to show. As before heat Z (1070° C.) gives very coarsely crystalline fracture with columnar border which is still stronger in heat 8 (1200° C.), Fig. 14.

Fig. 5, the fractures for steel 5. C. = 1.04, shows a marked change from the above. The fracture of the steel as rolled is like that shown in Fig. 15; has a dull center and is quite different from Figs. 12 and 7. This center persists as far as heat 1, which gives the finest structure. Beyond this the grain becomes slightly coarser, till at heat 4 (855° C.) there is a sudden change to a very coarse fracture, and this coarseness increases to heat 8 (1200° C.).

Fig. 6, fractures for steel 6. C. = 0.70, is akin to Fig. 5. As rolled the fracture shows a dark center, Fig. 15, larger than that of steel No. 5. This dark center can be seen as far as heat 6 (760° C.), in Fig. 17. Heat 1 (715° C.) Fig. 16 gave the finest fracture with a strong cup. With heat 2 (800° C.) there is a sudden change to coarseness which continues as far as heat 8 (1200° C.). Fig. 18 shows heat 5 (950° C.) which can be taken as the type.

From the above we see that the refining temperature* increases from 715° C. to 800° C. as the carbon content increases. Also the temperature of marked overheating rises from 800° to 1070° C. with the increase in carbon content.

MICROSTRUCTURE.

Cross sections, and where necessary longitudinal ones, were cut from each bar, polished in the usual way and etched with either a 2 per cent. solution of nitric acid in alcohol or a 5 per cent. picric acid in alcohol. The sections were first examined under a low power, 44–88 diameters and then under a higher magnification, 260–500 diameters. Over 100 photo-micrographs were taken but by choosing types these have been reduced to 30 in the present paper.

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*As judged by the fracture. This does not mean size of grain of the original steel (before pulling,) because pulling has reduced the cross section of the grain.

Steel No. 1. *C.* = 2.04.

As rolled, the steel consists of patches and veins of cementite surrounded by pearlite, much of which is in the sorbitic or unsegregated condition. Fig. 28 may serve as type. Size of grain medium. A narrow band round the edge shows good cell-walls of very fine cementite surrounding the pearlite grains. These in a longitudinal section are slightly elongated in the direction of rolling, whilst the interior shows long veins of cementite. Therefore, rolling was finished after the beginning of the separation of cementite, Ar_{2-3}.

Heated to 650° C. Fig. 19 x 260. The cementite veins have broken down and the structure is now granular except round the edge of the specimen.

Heated to higher temperatures the cementite becomes more and more globular, whilst the specimen heated to 760° C. shows a change in the pearlite. There is a certain amount of decarburization on the outside and this increases with the temperature. Heated to 950° C., the specimen shows this well in Fig. 20 x 44 diameters and taken at the corner of the specimen. The dark border consists of pearlite with long veins of cementite, producing a columnar structure and giving rise to the crystalline border of the fracture of the test-piece. At the extreme edge (surface) ferrite makes its appearance. The normal structure of the bar is shown by Fig. 21 x 260 and consists of granular cementite in pearlite.

Heated to 1070° C. the structure shows a marked change. The columnar border is now thick and consists of coarse pearlite with a thin skin of ferrite. Within this border we have coarse and globular cementite in coarse pearlite, Fig. 23 x 260. The center of the specimen, however, has undergone the marked change. It is composed of very coarse pearlite with a few veins of cementite and much graphite. The junction between this central portion and the normal is shown in Fig. 22 x 44.

Heated to 1200° C. the structure shows the change to be complete. In the centre the cementite has broken down into graphite and ferrite, much of which has been absorbed by the pearlite. This is shown in Fig. 24 x 260. Around this central portion occurs a zone, consisting of very coarse grained pearlite, surrounded

by irregular walls of cementite, Fig. 25 x 26. Beyond this zone decarburization has come into play and as the carbon decreases we get, first, a band of coarse pearlite, then a mixture of pearlite with increasing ferrite. The complete section from central core to edge is shown in Figs. 26 and 27 x 44 diameters. On the left we have the graphite zone, next the zone of cementite veins; in the center of Fig. 27 we have pearlite alone, whilst on the extreme right we have the corner of the specimen, a mixture of ferrite and pearlite

Steel No. 2. C. = 1.94.

As rolled the steel consists of patches and veins of cementite in a groundmass of sorbitic to fine pearlite, Fig. 28 x 260. The difference between this section and that of steel 1 as rolled, lies in the fact that here we have fewer patches of cementite.

Heating to higher temperatures produces the same changes as in steel No. 1, the cementite becomes more and more globular, whilst heating to 760° C. completes the change of the pearlite from the sorbitic to the granular form. The higher the temperature of heating above the critical point the coarser the grain of the pearlite and the deeper the decarburization.

Heated to 950° C., the normal structure is shown in Fig. 30 x 260. Examining the fracture we see a thin zone just beneath the surface which appears black. Under the microscope the changes show up well. Fig. 29 x 44 is a photograph from near the surface. The lower part shows the normal structure (see Fig. 30). At the surface we see the thin band of columnar pearlite with an excess of ferrite outside and of cementite inside as shown in Fig. 27. But between this outer band and the normal part of the specimen lies a zone, consisting of a groundmass of pearlite within which lie kernels of graphite, surrounded by shells of ferrite, shown in Figs. 34 and 35. Here we have just the reverse of that shown in Fig. 22, steel No. 1, heated to 1070° C.

Heated to 1070° C. we find in the center the same structure as shown in steel No. 1. Decarburization has produced a comparatively thick columnar border the outside of which is rich in ferrite as in Fig. 27. Within, we have a core of pearlite, containing ferrite-graphite kernels, Fig. 32 x 44, surrounded by pearlite with globular cementite, Fig. 31 x 260, outside of which comes a second

zone containing ferrite-graphite kernels. In this latter, the specimen differs from steel No. 1.

Heated to 1200° C. we have the change of the cementite complete. In the center lies the coarse pearlite with ferrite-graphite kernels. Outside comes the thick columnar border as in steel 1. The ferrite-graphite kernels are shown in Fig. 34, some very large ones in Fig. 35, whilst the structure of the cementite of the outer zone is shown in Fig. 33, all being x 260.

Steel No. 3. C. = 1.72.

As rolled, the structure shown in Fig. 37 x 260 consists of medium-sized grains of pearlite, surrounded by irregular envelopes of cementite, in contrast with steels No. 1 and 2. The pearlite varies from well-laminated to sorbitic.

Heating to 650° C. causes a marked change. Fig. 38 x 260 shows the veins of cementite breaking down and tending to take a globular form. There is a change in the pearlite also.

Heating to higher temperatures causes the same changes as before, Fig. 39 showing the structure of the bar heated to 855° C., which consists of granular or globular cementite in pearlite, whose structure in places is granular. Figs. 37, 38 and 39 show this progressive change in the structure of the cementite very well.

Heated to 950° C., the columnar border of coarse pearlite, etc., due to decarburization, is thicker. The junction between this and the normal part of the section is shown in Fig. 40 x 260, the decarburized part being above. In the center some of the cementite occurs as veins.

Heated to 1070° C., the columnar border becomes much thicker, while the center has undergone a complete change. It now consists of coarse pearlite with ferrite-graphite kernels and stray threads of cementite. It can be well compared to steels 1 and 2, heated to 1200° C.

Heated to 1200° C. a complete change occurs. The decarburized outer layer, of course, is the same as before, but the interior consists of very large grains of coarse pearlite, surrounded by thick walls of cementite as seen in Fig. 41 x 260. The cell-like structure is better seen in Fig. 42 x 44. Comparing this with steels 1 and 2, heated to 1200° C., it seems that we have here passed into a region which they have not reached.

Steel No. 4. C. = 1.61.

As rolled the structure is similar to that of steel 3, Fig. 37, with pearlite laminated to sorbitic.

Heating to 650° C. almost obliterates the cell walls of cementite and changes the pearlite entirely into the granular variety. As the temperature of heating increases the cementite becomes more and more globular and the decarburized layer on the outside begins to show above 760° C. heat.

Heated to 855° C., the cementite is very globular, as shown in Fig. 36 x 260.

Heating to 1070° C. brings about a very marked change. The columnar border is now thick and as before, at surface consists of ferrite (as on right of Fig. 45) but within is made up of elongated pearlite grains with cementite envelopes. The center of the section consists of large grains of pearlite with thick cementite walls, shown in Fig. 43 x 260 and 44 x 44. Around this central core lies a zone of pearlite with graphite-ferrite cores, much of the ferrite of which has been absorbed by the pearlite, Fig. 46 x 260.

Finally heating to 1200° C. produces the same change as in steel No. 3. The section shows the thick columnar border surrounding the core of coarse cementite and pearlite as seen in Fig. 47 x 260. The grain is better seen under lower powers as in Fig. 48 x 44. In this it is noticed that the cementite has separated out as long rods or plates within the grain of the pearlite as well as around it.

SUMMARY OF CHANGES OF STRUCTURE STEELS 1–4.

Leaving out of consideration the changes brought about by the decarburization of the outer layers of the steel—which first shows at 760° C., becomes noticeable at 800° and probably gives the crystalline border to the fracture of the test-piece, whilst at 1200° C. it has penetrated deep into the steel—we note several marked changes due to heat treatment rather than loss of carbon.

Change in the Pearlite.—As rolled the pearlite is either very finely laminated or in the sorbitic condition. Heating to even 650° C. causes a change and the pearlite tends to become granular. Higher temperatures make it coarser. Again at 760° C. it is refined

as regards its grain size, and heating to temperatures above this produce larger and larger grains.

Change in the Cementite.—As rolled the cementite appears as veins or patches. Heating to 650° C. and above causes the cementite to tend to take a globular form. The higher the temperature the more the segregation. But as the temperature rises above 760° C. (the critical point Ac_1 in reality) the cementite also tends to dissolve in the solid solution formed by the transformation of the pearlite (and called hardenite, martensite, austenite, etc.). On cooling down again all of this dissolved cementite separates out, as a rule on the undissolved grains of cementite, but lacking these, around the grain of the solid solution as an envelope.

As the temperature rises a point is reached where any undissolved cementite is no longer stable, but breaks down, forming a kernel of graphite with a shell of ferrite. When we examine Figs. 24, 34, 35 and 46, it seems that in these experiments but little cementite has been dissolved, most of it having broken down into ferrite and graphite. This might be explained by assuming that the power of segregation of the cementite is stronger than that of solution, possessed by the solid solution, austenite. We cannot explain, however, why graphite forms in one part of the section and not in another, presumably at the same heat. In fact, Arnold* cites a case where in a 2-inch bar the graphite separated in annular rings. This apparently happened in steel No. 2, heated to 1070° C., where we find graphite in the center and also just beneath the decarburized layer. After going very carefully over other sections, some graphite was found in the center of the bars as rolled both in steel No. 2 and No. 1, and evidently the results of rolling. A possible explanation for this central graphite, Figs. 22 and 32 is that all or part of it is due to the effects of rolling. The cause of the outer zone of graphite seen in Figs. 29 and 46 is the same as that of Figs. 24, 34, etc., viz: instability of cementite at some temperature. The temperature of this change evidently varies, for the change occurs in the 1200° heat for steel 1, but began at 950° C. in steel 2; in steel 3, it occurs strongly in the 1070° C. heat, while in steel 4 in the 1070° C. heat it is almost covered by the next change.

* Journal I. and S. Inst. 1905, II., p. 46.

Lastly we come to that change whereby the whole of the cementite or carbon is taken into solution and is thrown out around the grains of the solid solution on cooling. The resulting structure is seen in Figs. 42, 44 and 48. This change began in the 1070° C. heat for steel No. 4, but requires a heat over 1200° C. for steel No. 1.

Thus we see that whereas the change which occurs in the pearlite is constant at Ac_1, the changes due to the decomposition and solution of cementite are variable.

Steel No. 5. *C.* = 1.04.

The changes which take place in those last two steels are comparatively simple, because we find no separation of graphite.

As rolled the section consists of pearlite alone, in medium sized grains, whose texture varies from very fine to coarse.

Heating to 650° C though not changing the size of the grains, produces granular pearlite with minute dots of cementite which polish in relief.

Heating to 760° C produces a change in the pearlite and the cementite shows up in larger spots. Decarburization of the edge now noticed.

Heating to 800° C. causes a growth of the pearlite grain and now the cementite in excess of the entectoid ratio appears as a thin envelope around the pearlite.

Heating to 855° C. produces strong decarburization and coarsens the pearlite considerably. The cementite has disappeared. Temperatures above this produce a coarser and coarser grain structure, with increasing decarburization at the surface. The texture of the pearlite also becomes extremely coarse.

From the above it is seen that the changes are quite simple. The steel as rolled is richer in cementite than the usually recognized saturation point, 0.9 per cent. This excess, however, separates out on heating.

Steel No. 6. *C.* = 0.70.

As rolled the section shows a thin border with some ferrite. The rest consists of pearlite in medium sized grains with very thin ferrite veins which disappear towards the center. Much of the pearlite is sorbitic.

Heated to 650° C., the steel shows a change in the pearlite which continues with the increase in temperature, till at 760° C. it shows the normal pearly appearance. In places there is marked segregation of cementite in the pearlite, producing very coarse lamination.

Heated to 800° C., there is a great increase in grain size. The ferrite now occurs as grains, not as veins and the pearlite is very coarsely laminated. With increase in temperature we get an increase in size of grain and in decarburization of the outer layers. Thus steel 6 shows overheating at as low a temperature as 800° C.

RELATION BETWEEN THE PHYSICAL PROPERTIES, FRACTURE AND MICROSTRUCTURE.

It has been noted that for the series of steels worked with, heating to temperatures up to the critical point Ac_1 lowers the strength and increases the ductility. Examining the fractures, there is no marked change in size of grain until we reach the critical point. The microstructure shows us that this treatment causes (1) a breaking down of the veins of cementite which tends to take a globular form (2) a change in the character of the pearlite. The size of grain of the pearlite does not change until the critical point has been passed. Therefore, it is necessary to heat to a temperature just above Ac_1 for complete refining.

In the case of steels 1 to 4 or those high in carbon, heating to temperatures above the critical point had but little effect on the strength as compared with that of the refined bars, until the maximum heat (1200° C.) was reached, when overheating occurred to such an extent that the tensile strength fell to less than 70,000 pounds per square inch. The ductility, however, steadily declined to almost zero.

The fractures show a steady increase in size of grain until at the 1070° C. heat we have a sudden change to very coarse, accompanied by a change in color due to separation of graphite. The microstructure shows a steady increase in the grain and texture of the pearlite, with increase in the segregation of the cementite, until at heat Z (1070° C.) we find the cementite breaking down into ferrite and graphite, and the pearlite extremely coarse. The rapid fall in strength for the maximum heat (1200° C.) can be

accounted for in steels 3 and 4 by the further change, producing coarseness of grain and thickness of cementite envelopes, but for steels 1 and 2 the reason is not so clear. It seems to be mainly due to extreme coarseness of grain.

In the case of steels 5 and 6 or those lower in carbon, heating to temperatures above the critical point if anything improves the strength as compared with that of the refined bars. The ductility falls, however, rapidly at first, then slightly.

Examining the fractures, steel 5 shows overheating at heat 4 (855° C.) while steel 6 is overheated at 800° C. Both of these temperatures seem very low. The microstructure shows a steady increase in texture and grain size of the pearlite, with perhaps, some slight acceleration at these two temperatures.

Thus we see that each change in the physical properties is accompanied by an equally marked change, both in character of fracture and in microstructure, and the relation between the three is absolutely binding. It may be said that the amount of decarburization through the use of such small sections would seriously interfere with the results obtained. But a moment's consideration will show that results obtained with these bars would be far more striking and emphatic when thicker bars are used. In order that undue emphasis might not be laid on the results of the physical tests, the curves have all been plotted on as small a vertical scale as possible. However, a new series of 6 steels is already on hand (ranging from 1 to 2 per cent. carbon in equal steps) of $\frac{3}{4}$ inch diameter and it is hoped to continue the work with them.

LIST OF ILLUSTRATIONS.

Fractures of Test-pieces, Arranged According to Heat-treatment.

Fig. 1.	Steel No. 1. C. = 2.04	A = as rolled	
Fig. 2.	" No. 2. C. = 1.94	3 = Heated to	650° C.
Fig. 3.	" No. 3. C. = 1.72	1 = " "	715° C.
Fig. 4.	" No. 4. C. = 1.61	6 = " "	760° C.
Fig. 5.	" No. 5. C. = 1.04	2 = " "	800° C.
Fig. 6.	" No. 6. C. = 0.70	4 = " "	855° C.
		0 = " "	905° C.
		5 = " "	950° C.
		Z = " "	1070° C.
		8 = " "	1200° C.

Single Fractures Magnified 6 Diameters.

Fig. 7.	Steel No. 1.	C.=2.04.	as rolled.	
Fig. 8.	"	"	Heated to	800° C.
Fig. 9.	"	"	" "	950° C.
Fig. 10.	"	"	" "	1070° C.
Fig. 11.	"	"	" "	1200° C.
Fig. 12.	Steel No. 4.	C.=1.61.	as rolled.	
Fig. 13.	"	"	Heated to	760° C.
Fig. 14.	"	"	" "	1200° C.
Fig. 15.	Steel No. 6.	C.=0.70	as rolled.	
Fig. 16.	"	"	Heated to	715° C.
Fig. 17.	"	"	" "	760° C.
Fig. 18.	"	"	" "	950° C.

PHOTOMICROGRAPHS.

Steel No. 1. C.=2.04.

Fig. 19. Heated to 650° C. shows coarse patches of cementite in dark matrix of pearlite, x 260.

Fig. 20. Heated to 950° C. shows the corner of specimen with decarburized outer layers, x 44.

Fig. 21. Shows the same x 260, globular cementite in dark matrix of pearlite.

Fig. 22. Heated to 1070° C. central part of section x 44.

Fig. 23. Same as lower part of Fig. 22 x 260, shows coarse globular cementite in coarse pearlite.

Fig. 24. Heated to 1200° C. shows graphite in very coarse pearlite, x 260.

Fig. 25. Heated to 1200° C. Irregular veins of cementite surrounding very large grains of coarse pearlite, x 260.

Fig. 26. Shows the last two Figs. x 60. On the left we have graphite in pearlite, on the right cementite in pearlite.

Fig. 27 is a continuation of the same section to the corner. On the left is cementite in pearlite, in the center is pearlite alone whilst the right of the figure shows ferrite, making its appearance at the corner of the section, x 44.

Steel No. 2. C.=1.94.

Fig. 28. Shows the structure as rolled, x 260. Irregular veins and patches of cementite in a dark matrix of pearlite.

Fig. 29. Heated to 950. Shows the side of the specimen, x 44. The lower part shows the normal cementite in pearlite. Above this occurs a zone of graphite in pearlite, capped by the decarburized outer layer of ferrite and pearlite.

Fig. 30. Shows the center of Fig. 29 x 260. globular cementite in pearlite.

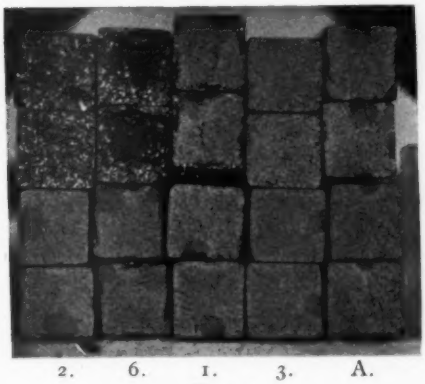
Fig. 31. Heated to 1070° C. center of section, x 260.

8. Z. 5. o. 4.

2. 6. 1. 3. A.

FIG. 1.

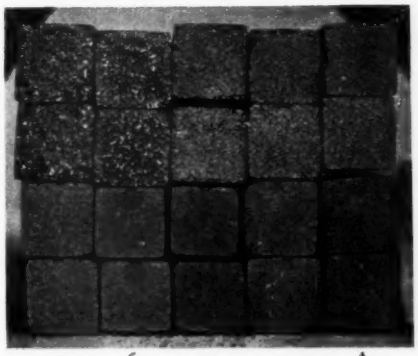
8. Z. 5. o. 4.



2. 6. 1. 3. A.

FIG. 2.

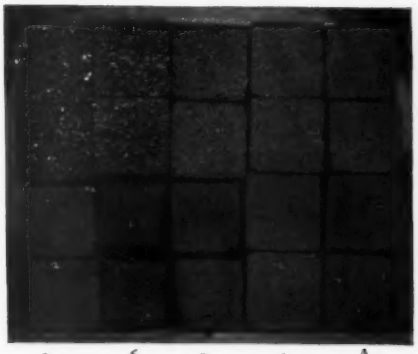
8. Z. 5. o. 4.



2. 6. 1. 3. A.

FIG. 3.

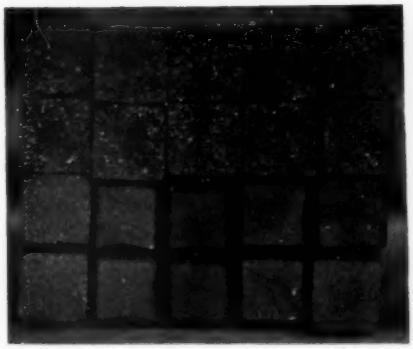
8. Z. 5. o. 4.



2. 6. 1. 3. A.

FIG. 4.

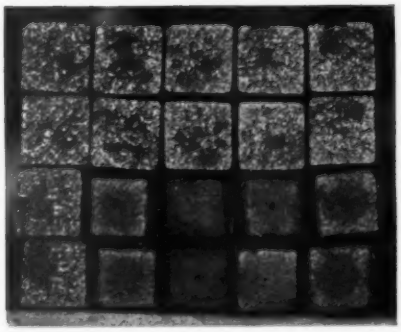
8. Z. 5. o. 4.



2. 6. 1. 3. A.

FIG. 5

8. Z. 5. o. 4.



2. 6. 1. 3. A.

FIG. 6

FIG. 7.—Steel 1 A. C = 2.04

FIG. 8.—1^2 to 800° C.

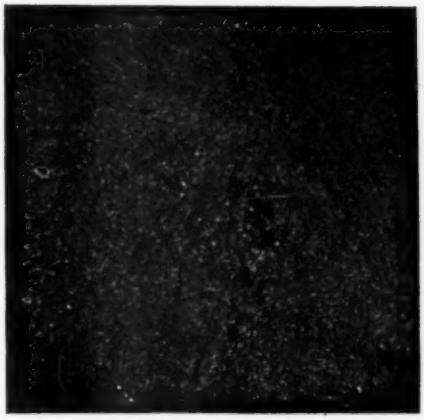


FIG. 9.—1^5 to 950° C.

FIG. 10.—1^2 to 1070° C.

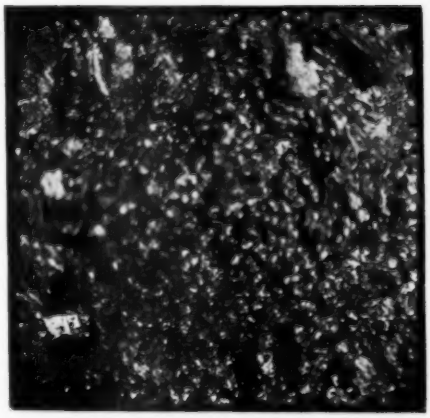


FIG. 11.—1^8 to 1200° C.

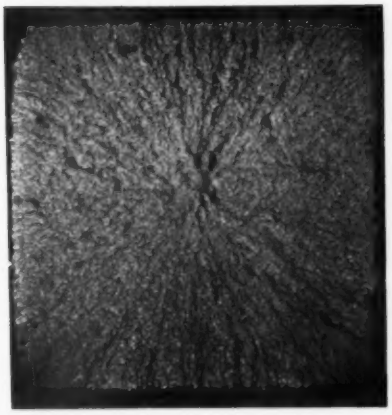


FIG. 12.—Steel. 4A. C = 1.61.

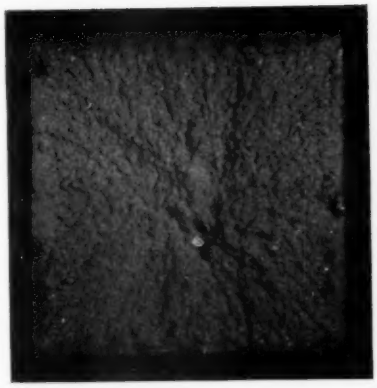


FIG. 13.—4^6 to 760° C.

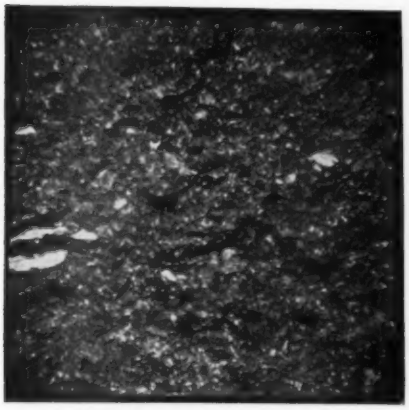


FIG. 14.—4^5 to 1200° C.

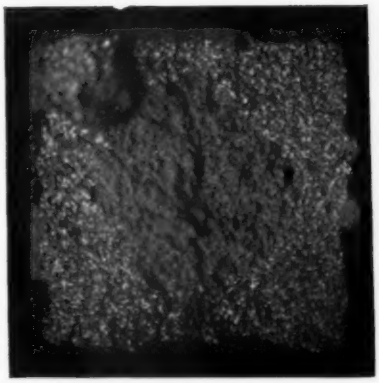


FIG. 15.—Steel 6^A. C = 0.7.

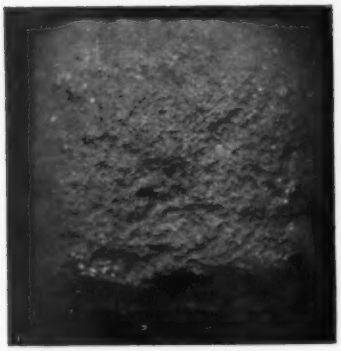


FIG. 16.—6^1 to 715° C.

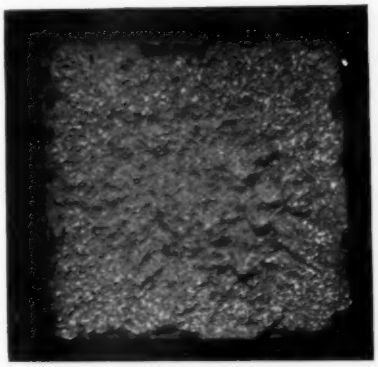


FIG. 17.—6^5 to 760° C.

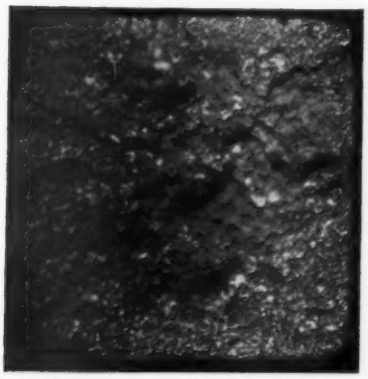


FIG. 18.—6^5 to 950° C.

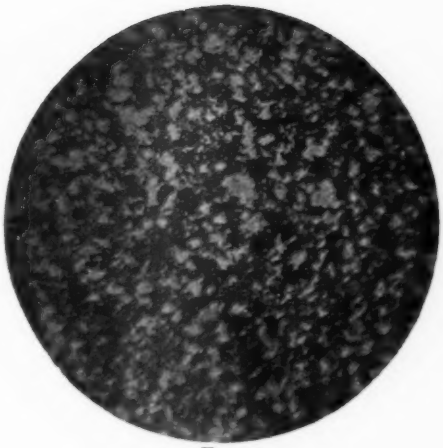


FIG. 19.

FIG. 20.

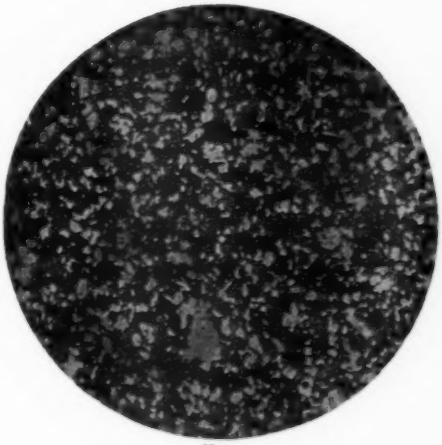


FIG. 21.

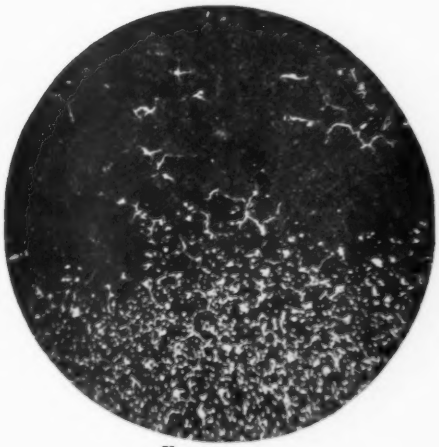


FIG. 22.

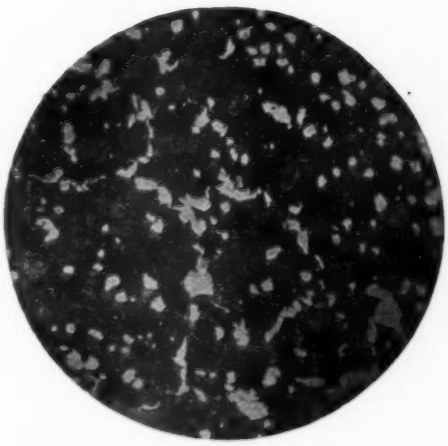


FIG. 23.

FIG 24.

FIG. 25.

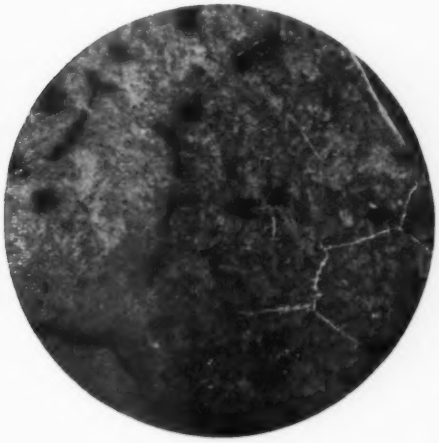


FIG. 26.

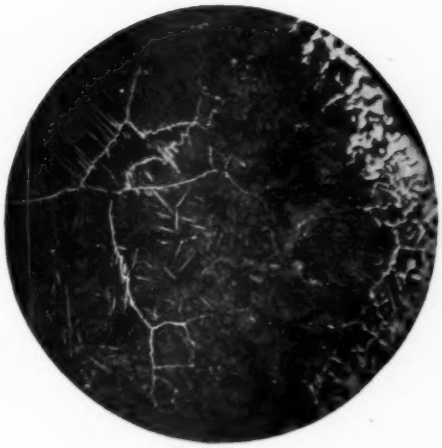


FIG. 27.

FIG. 28.

FIG. 29.

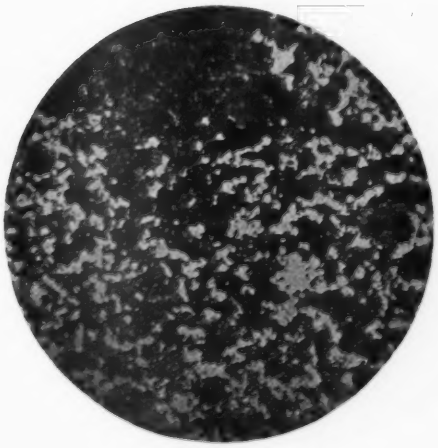


FIG. 30.

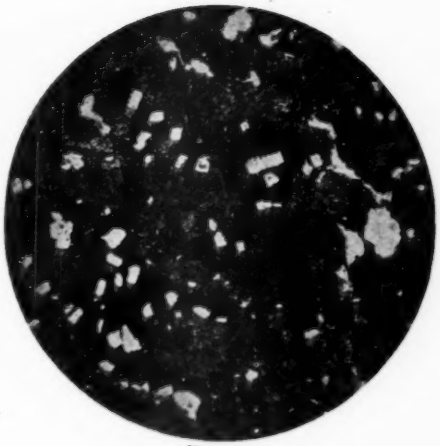


FIG. 31.

FIG 32.

FIG. 33.

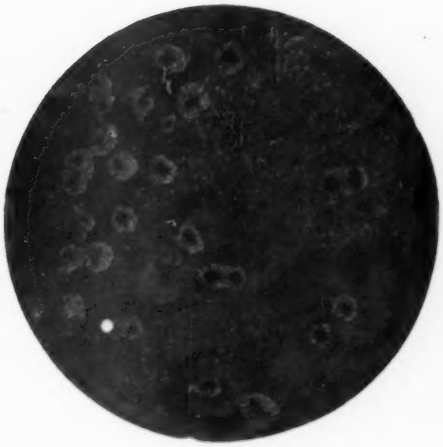


FIG. 34.

FIG. 35

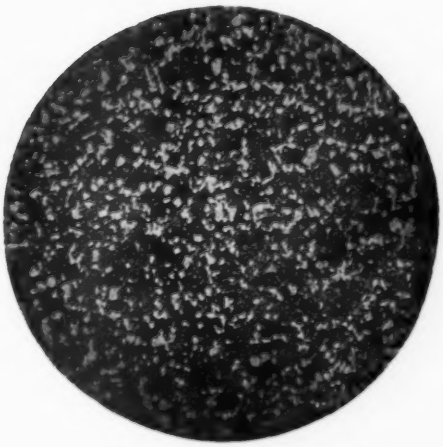


FIG. 36.

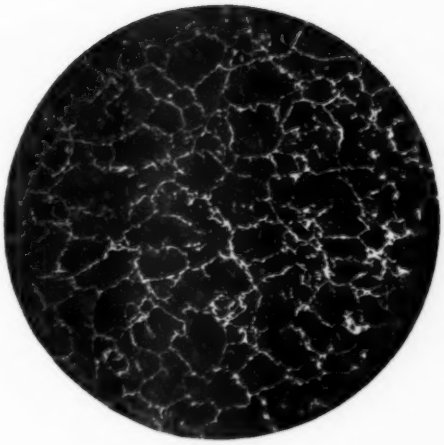


FIG. 37.

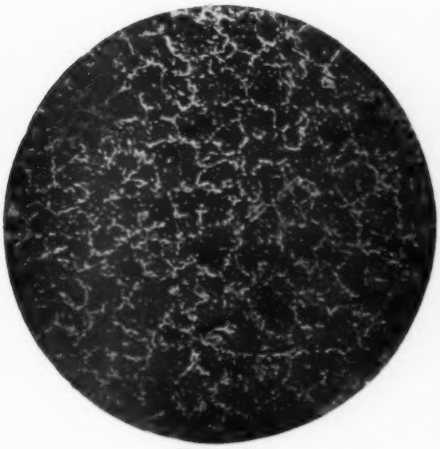


FIG. 38.

FIG. 39.

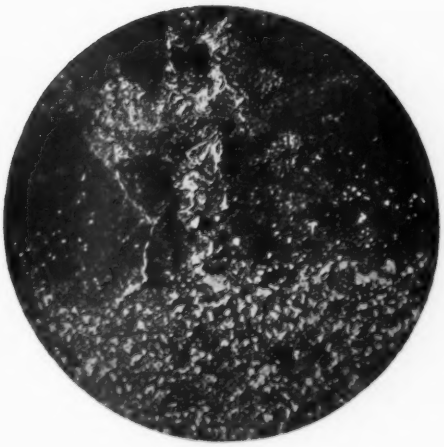


FIG. 40.

FIG. 41.

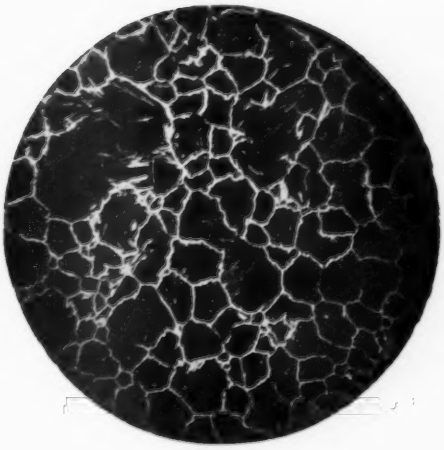


FIG. 42.

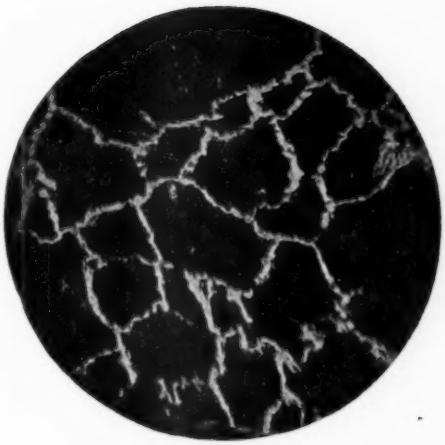


FIG. 43.

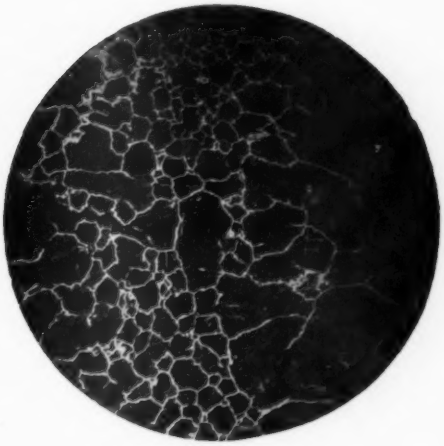


FIG. 44.

FIG. 45.

FIG. 46.

FIG. 47.

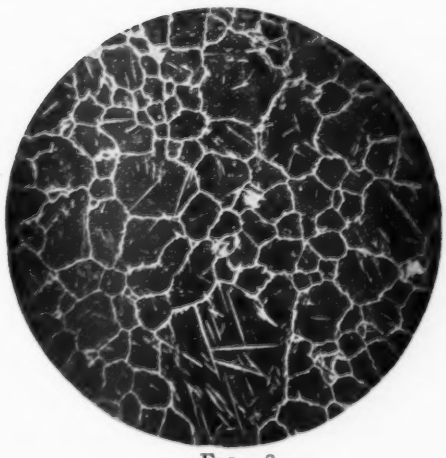


FIG. 48.

Fig. 32. Shows same x 44, shows both graphite and cementite in pearlite.
Fig. 33. Heated to 1200° C. x 260, shows irregular veins of cementite in coarse pearlite.
Fig. 34. Same section, showing graphite kernels with ferrite shells in matrix of pearlite.
Fig. 35 shows some coarse examples of same.

Steel No. 3. $C.=1.72$.

Fig. 37 shows the structure as rolled, x 260, a network of cementite in matrix of pearlite.
Fig. 38. Heated to 650° C. The cementite network is starting to break up, and take globular form, x 260.
Fig. 39. Heated to 855° C. Globular cementite in pearlite, x 260.
Fig. 40. Heated to 950° C., shows edge of specimen x 260. The lower part is normal globular cementite in pearlite while the upper part is coarse pearlite alone.
Fig. 41. Heated to 1200° C., shows very coarse irregular veins of cementite in pearlite, x 260.
Fig. 42 shows the same, x 44 diameters. The size of grain is extremely large.

Steel No 4. $C.=1.61$.

Fig. 36. Heated to 855° C., shows globular cementite in pearlite, x 260.
Fig. 43. Heated to 1070° C., coarse pearlite grains surrounded by cementite veins, x 260.
Fig. 44 shows central part of same, x 44.
Fig. 45 is a continuation of the section to the edge of the specimen, seen on the right by the appearance of ferrite, x 44.
Fig. 46. Heated to 1070° C., shows graphite in pearlite, x 260.
Fig. 47. Heated to 1200° C., shows very coarse and irregular cementite in pearlite x 260.
Fig. 48 shows same, x 44.

ACKNOWLEDGMENTS.

To the Carnegie Institution of Washington my sincere thanks are due for a grant, to carry on the work. To Henry M. Howe and my other friends I owe much for encouragement and advice.

DISCUSSION.

Mr. Christie.

MR. JAS. CHRISTIE.—Can Dr. Campbell tell us something about the effect of prolonged heating on his specimens?

Were the specimens held briefly at the high temperature, or was the heat maintained for a considerable period? For annealing eye-bars for bridges, it is now customary to use much higher temperatures than formerly. It was sometimes specified that the bars should be heated to the temperature of recalescence or where the magnetic property disappeared, or approximately 1300 to 1400° F. This temperature has been found insufficient. Better results are obtained at 1600 to 1800° F, in fact, even higher temperatures are advantageous.

Of course the bars are not held long at this temperature. The question of time arises, and would this account for the faulty structure of bars rolled at temperatures no greater than is frequently used for annealing, or is the defective structure residual from the initial casting heat?

Mr. Campbell.

MR. WILLIAM CAMPBELL.—The heating was done in a gas furnace and so arranged that the maximum temperature was reached in one hour, as nearly as possible, and specimens were kept there for about five minutes. Seeing that they are only $\frac{5}{16}$ inch square, I assumed that five minutes would be ample time for them to reach the same temperature from outside to center. Then the gas was turned off and the furnace was allowed to cool down slowly. It took from three to four hours for the whole to cool down sufficiently to be handled.

Mr. Bostwick.

MR. W. A. BOSTWICK.—Mr. Christie has touched upon a point that is very interesting to those having to deal with the heat treatment of large masses, and that is the time factor that is necessarily introduced. As Mr. Christie has said, in the modern practice of making eye-bars temperatures are used for annealing that are far beyond any annealing temperatures formerly used. There is undoubtedly the element of time and mass, or, as it might be called lag, that enters very largely into this question. I think, if it were possible to conduct a series of experiments that would

show the effect of this factor of mass and time, it would be of enormous benefit to those engaged in manufacturing. I have personally seen some very remarkable demonstrations of this question of mass, and I should be very glad to get further information on the subject. **Mr. Bostwick.**

MR. J. A. KINKEAD.—Mr. Christie and Mr. Bostwick have both brought up the element of time, which enters into the heating of steel as well as other factors. In commercial work the temperature of the furnace and not of the material is generally taken; whereas, while the temperature of the furnace may be 1500 to 1700 degrees, the material in the furnace, if of sufficient bulk, may be 150 or 200 degrees lower in temperature. I have known of the annealing of steel castings where the results would be attained at 1400 degrees, whereas, the pyrometer registered over 1500 degrees, showing absolutely that the charge was at least 100 degrees behind the temperature of the furnace; and that might be true also in the annealing of eye-bars. **Mr. Kinkead.**

MR. CHRISTIE.—I would just say, Mr. Chairman, that the method used is to show the temperature of the bar and not of the furnace; that is, the exterior of the bar. It may be different in the interior, as far as we know. **Mr. Christie.**

MR. BOSTWICK.—Mr. Christie has also referred to eye-bar steel as being of very different carbon content from the steels investigated by the author. I have had a little experience with high-carbon ordinary steels used in rolling mill work, the mill parts, pinions, rolls, etc., and pretty careful investigations have been conducted to determine the best method of heat treatment to insure the best service. This question of lag, as I call it, is a very important factor. Heating has been done very carefully on masses say 30 to 36 inches in diameter, covering periods ranging from two days to ten days, the heat then being maintained at the various temperatures for a sufficient length of time to insure absolute uniformity; and notwithstanding that, the theoretical annealing points were never realized in securing good results. The greater the mass, apparently, the higher the temperature required to insure the fineness of structure necessary for good service. Possibly Mr. Acker may be able to confirm some of this. **Mr. Bostwick.**

MR. E. O'C. ACKER.—Those of us who have had to deal with heat treatment of large masses of steel have been more or less **Mr. Acker.**

Mr. Acker. misled, I may say, by investigators who have been working on $\frac{5}{16}$ inch squares or other small sizes in the laboratory. It is, of course, impossible to formulate any general rules, because a mass dealt with may vary from 2 or 3 to 36 inches in diameter. Each size seems to be more or less a rule to itself, taken in combination with its composition and the results aimed at. We also find the alloy steels have their own peculiarities, which makes the subject still more complicated. But I think that as far as the difference between furnace temperature and the temperature of the pieces is concerned, more or less confusion has been introduced by the use of the electro-pyrometer, and only because pieces have not been allowed to go to full heat. With the use of the Siemen's water pyrometer, by keeping the copper or iron ball in contact with the piece and protecting it from radiation from the furnace, we can generally insure a correct observation of the temperature of the piece. Of course that is a matter of time and experience. But for some reason or other, as Mr. Bostwick has said, we are not able to get the same results from larger pieces as from smaller ones, even when we are sure of uniform heating. I think possibly that may be accounted for by the rapidity of cooling, the larger pieces holding their heat for a considerably longer time, do not seem to be affected by the heat treatment to the same extent as smaller pieces. For instance, we all know that with a piece 2 or 3 inches in diameter, we can get very much better results from heat treatment than with a piece 8 or 10 inches in diameter, no matter how carefully we treat it. I should just like to ask one question of Professor Campbell, and that is, in the higher carbon steel, the 1.94 and 2 per cent. carbon steel after he had changed the cementite to graphite, was he able to change the graphite back again to cementite?

Mr. Campbell. MR. CAMPBELL.—I haven't got that far yet. I certainly do know that in the 1.72 and 1.61 per cent. carbon, where the graphite came out as microscopic flakes, heating up to 1200° C. changed it back into the form of cementite again; and I think it is pretty well known among the manufacturers of steel cutlery that in certain cases where they get a black steel due to the separation out of graphite, on heating up to a high temperature, the carbon is changed from the form of graphite into cementite again.

Mr. Moldenke. MR. RICHARD MOLDENKE.—This seems to be touching upon

the malleable cast iron practice. Here we have the constant experience of getting the carbon in the iron from the combined state into the amorphous or graphitic. Then, if we heat the casting red hot and quench rapidly, the carbon becomes combined again. There is no difficulty whatever in carrying this out in the "malleable" foundry. Mr. Moldenke.

THE CHAIRMAN (MR. H. M. HOWE).—I did not understand Dr. Campbell to say that in any case he actually saw graphite with his own eyes, turned into cementite and then back into graphite, but I think he did practically say the same thing. His steel if heated to 900 and 1070° C. showed graphite, if other like bars of that same steel were heated to 1200° C. they then showed no graphite. Now these latter bars, in heating up to 1200° C., must have passed through 1070° C. and, therefore, it is altogether probable that graphite was formed, and as it was not found on cooling the bars, it was probably reabsorbed between 1070 and 1200° C. The Chairman.

Dr. Moldenke perhaps could help us on that question, whether in annealing malleable castings, if the temperature is raised higher than the proper annealing temperature, but still not high enough to melt the castings, you would then get the formation of graphite, or whether the graphite is reabsorbed, as in Dr. Campbell's case.

MR. MOLDENKE.—Whenever we have had the misfortune to let the temperature of our annealing ovens go too high, the castings in them would be ruined. On breaking them, instead of having a black velvety structure, they would be white and coarsely crystalline, the structure being entirely different from the white crystalline fracture of the original hard casting as it comes from the sand. It was impossible to get this material back into proper shape again, and it had to be counted a dead loss for everything except the blast furnace. The range of temperature for annealing is very close and cannot be exceeded without damage, or fall below and give satisfactory results. In the latter case the work can be done over again; in the former it is hopeless. Mr. Moldenke.

MR. JAMES A. BECKETT.—I think that the assertion made by Dr. Moldenke is absolutely true; no matter how good a malleable iron casting you make, as soon as it is heated to a cherry red and plunged into cold water it becomes white and more or less as it was before it was annealed. Mr. Beckett.

Mr. Beckett. This tendency frequently causes trouble in manufacturing where malleable iron is used, because when it is of irregular form, it gets crooked in annealing and has to be heated in order to straighten it between cast iron dies, after which, if it is cooled off too rapidly it becomes hard and unfit for use.

Mr. Moldenke. MR. MOLDENKE.—Malleable castings must never be straightened hot, especially when thick. In the case of very thin castings there is some latitude, as the material is so decarbonized that it is nearer a steel than genuine malleable cast iron. We at one time had a lot of heavy castings which were warped in anneal. I advised against straightening them hot, but this was done to save time, with the result that most of them came back broken after a time. It seems that in heating up the portions of the castings which were badly warped, the amorphous carbon in them was combined again, and while the balance of the casting remained black and sound, the heated parts became white and brittle as in the original hard casting. Hence the advice to straighten the castings cold, preferably with a drop hammer and suitable dies, or still better in the hydraulic press.

Mr. Bostwick. MR. BOSTWICK.—The question of lag that I referred to is not lag in temperature, but lag in the molecular adjustment of the structure of the whole piece.

The Chairman. THE CHAIRMAN.—It is very natural that it would take longer to travel a quarter of a mile than to travel an inch; and in these large ingots, with very slow cooling, very coarse crystals, you have traveling through to the center large crystals instead of small crystals, and of course that travel ought to take a long time. I may say that even with small bars we have reached some very puzzling results in that way. We find by heating to ordinary temperatures which give a great improvement in refining or restoring steel, when we heat it very slowly and cool it very slowly we apparently did not get any restoring. Now we have not gone far enough yet to make sure whether that was the case. We may have been misled by first appearances. But those indications were that very slow heating and cooling did not at all give us the benefit we expected to get, and did get, under ordinary conditions by heating and cooling at a moderate rate.

The reason we experiment with $\frac{5}{16}$ inch bars, which we regret very much, is that we have to proceed from the simple to the com-

plex. We have to first determine the laws of nature in the simplest form and we can proceed then to the more complex form. **The Chairman.**

MR. J. J. SHUMAN.—I should like to ask one question. Suppose a bar were spoiled, made crystalline by being rolled at too high a temperature; could that bar be restored to a good condition simply by heating it above the critcal temperature and allowing it to cool again? **Mr. Shuman.**

MR. CHRISTIE.—If by the term "spoiled" is meant that the crystalline structure is too coarse, and the metal brittle, there is no question that both iron and steel can be restored by heating to the proper refining temperature. In fact, that is the principal object attained by the heat treatment, known as annealing, a process that could advantageously be extended to a greater range of products than is customary. **Mr. Christie.**

MR. CAMPBELL.—The words "critical temperature of steel" have been mentioned. I should like to point out that there is only one steel with a single critical temperature, and that is one that contains between .8 and .9 carbon. All the others have two critical temperatures. In other words, nearly all the steel we use is built up of two substances, one ferrite and the other pearlite. The pearlite is refined by heating up to the recalescence point about 700° C. If you want to refine the ferrite you have got to heat it up to 800° C. or more. Then for the whole, you must heat the steel up to 800 ± degrees to refine the ferrite and after that to 700° C. to refine the pearlite. Of course this is not in a majority of cases practicable. The consequence is, we have to strike a happy medium and refine the pearlite and ferrite as much as possible by heating to some intermediate temperature between their two refining points. If we consider that steel is built of these two constituents, we will be able to understand our difficulties a great deal better, even if we are not able to overcome them. **Mr. Campbell.**

THE CHAIRMAN.—Referring directly to the question, I think there is no doubt that the injury done by overheating can be completely removed and steel can be completely restored, as far as is shown by microscopic and as far as is shown by ordinary tests, by reheating, provided the overheating has not gone so far as to cause actual mechanical defects. If it has gone so far as to cause cracks, then it is hopeless. No simple heating will close up mechanical cracks which have opened. Again, even if it has not gone so far **The Chairman.**

The Chairman. as to cause actual mechanical cracks, the farther the injury has gone the longer time and the higher temperature will be required to overcome it, for the reason to which Mr. Bostwick has called attention: the longer time needed to cause redistribution and de-segregating when this local segregation has itself distributed the metal unevenly about axes which themselves are far apart.

THE BURNING, OVERHEATING, AND RESTORING OF NICKEL STEEL.

By G. B. Waterhouse.

The following paper is based on an investigation conducted in the metallurgical laboratory of the School of Mines of Columbia University in the City of New York.

The author has much pleasure in acknowledging the ready counsel and aid of Professor Henry M. Howe, who planned the work of investigation, and under whose immediate direction it has been carried out; of Professor Bradley Stoughton, and the other members of his staff. Thanks are also due to Professor I. H. Woolson, of the Mechanical Engineering Department, Columbia University, for allowing the mechanical tests to be made in his laboratory.

Object of the Investigation.

The object of the following research is to ascertain the temperatures required to injure nickel steel by overheating, and to remove the injury thus caused, studying the changes by means of mechanical and microscopical tests.

Nothing is known of this subject by direct observation, and we have only the analogy of common steels.

The literature on the Burning, Overheating, and Restoring of Steel has been recently reviewed by the author.* The following definitions were proposed:

Burnt Metal.—Coarsely crystalline and exceedingly brittle iron or steel, in consequence of excessive heating; often with some inter-crystalline layers of oxide of iron. It cannot be effectively restored by heat treatment or mechanical work.

Overheated Metal.—Coarsely crystalline and brittle iron or steel, in consequence of excessive heating; with no inter-crystalline

* G. B. Waterhouse. The Burning, Overheating and Restoring of Steel. *Engineering and Mining Journal*, Vol. 81, 1906, pp. 386, 414.

spaces. It can be restored by heat treatment or mechanical work.

Restoring.—The operation of removing the injurious effects of excessive heating, and attempting to restore the initial or superior properties to the material.

The results arrived at were that steel becomes burnt on heating to a temperature above the line Aa in Fig. 1.

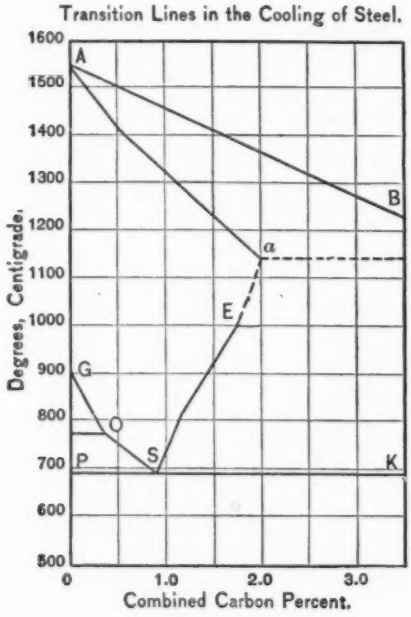


FIG. 1.

Such steel cannot be effectively restored. When heated to temperatures below Aa, steel may become overheated; from which condition it may be restored by heating to a temperature slightly above G O S E where solid solution is complete.

EXPERIMENTAL METHODS AND LINE OF RESEARCH OF THIS PAPER.

A series of seven crucible steels were taken in which the nickel was constant, the carbon rising from .41 per cent. to 1.52 per cent. and the other elements as low as possible.

The mode of preparation of these steels, and their properties under several conditions have been previously described by the author.* The analyses of the 1 inch diameter rolled bars are given in Table I.

TABLE I.

Mark of Steel.	K.	L.	M.	N.	O.	Q.	R.
Total Carbon, per cent.	.41	.51	.63	.79	.97	1.24	1.52
Nickel, per cent.	3.79	3.79	3.76	3.81	3.75	3.81	3.82
Silicon, per cent.	.102	.103	.133	.129	.095	.117	.144
Manganese, per cent.	.086	.054	.050	.051	.058	.057	.054
Sulphur, per cent.	.013	.014	.014	.014	.014	.014	.015
Phosphorus, per cent.	.007	.008	.008	.008	.008	.008	.007
Aluminium, per cent.	.010	.010	.009	.010	.011	.009	.010

The critical points are given in Table II.

TABLE II.

Mark of Steel.	K.	L.	M.	N.	O.	Q.	R.
Heating. Ac. 2.3 degrees Centigrade	744	734	.....	.....	.....	.....	.....
Heating. Ac. 1 degree Centigrade	704–714	699–714	702–717	703–718	701–716	688–698	683–693
Cooling. Ar. 3.2 degrees Centigrade	653–638	640	.....	.....	.....	.....	.....
Cooling. Ar. 1 degree Centigrade	608–598	615–605	610–600	612–602	612–602	620–610	621–611

As compared with carbon steels the transformation points, Ar 3, Ar 2, and Ar 1, have been lowered about 20° C. for every 1 per cent. of nickel.

To determine the overheating temperatures, bundles of bars, 10 inches long, consisting of one bar of each steel, were heated to 1000° C., 1100° C., 1200° C., 1300° C., 1400° C., and 1460° C. The heating was carried out in a gas fired crucible furnace, using the arrangement shown in Fig. 2. The time required to heat to the first four temperatures was 1 hr. 10 min., 1 hr. 45 min., 2 hr. 35 min., and 2 hr. 20 min., respectively. The bars, in all cases, were maintained for an hour at the desired heat, and cooled slowly in place. The mechanical tests of these bars were then made, and a section cut off for microscopical examination.

* G. B. Waterhouse. The Influence of Nickel and Carbon on Iron. *Journal Iron and Steel Institute*, No. II, 1905, p. 376.

The overheating temperatures having been ascertained, bars of each steel were heated to this temperature under similar conditions. Bundles were then made up as before of one bar from each steel, and these bundles reheated to 700° C. and 775° C., held there for one-half hour and cooled in the furnace. The reheating

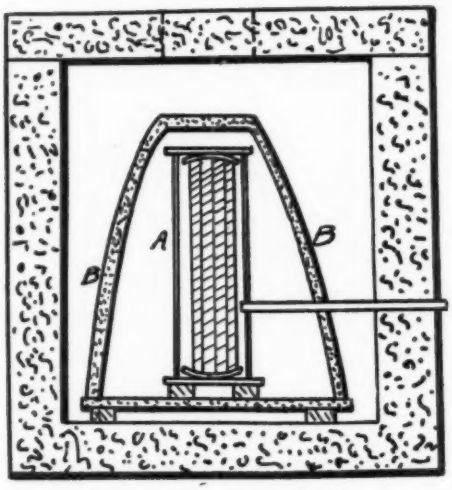


FIG. 2.—A, Mild Steel Pipe.
B–B, Graphite Crucible.

was carried out in a special gas-fired muffle furnace, designed by Professor Howe, of which a description is given in a paper by him, published simultaneously with the present one.

The results may be conveniently classified under the heads chemical, mechanical, and microscopical.

CHEMICAL.

The analyses of the steels have been given in Table I. The separation of temper graphite in the upper members of the series is very interesting. The results are given in Table III, including those published in the preceding work.*

* G. B. Waterhouse. The Influence of Nickel and Carbon on Iron. *Journal Iron and Steel Institute*, No. II, 1905, p. 376.

TABLE III.

Mark	Condition of Carbon.	Ingot.	Billet.	Rolled.	Treatment A. 1000°C., cooled in air.	Treatment B. 875° C., cooled slowly.	Heated to 1000°.	Heated to 1100°.	Heated to 1200°.	Heated to 1300°.	Heated to 1200°. Reheated 700°.	Heated to 1200°. Reheated 775°.
Q.	C. C.	1.24	1.24	1.24	1.24	1.24	.73	1.16	1.24	1.24	1.24	1.24
	Gr. C.	....	....	....	....	....	.51	.08	....	....	....	....
R.	C. C.	1.52	1.05	1.48	1.21	.50	.23	.29	.83	1.52	.54	.53
	Gr. C.	....	.47	.04	.31	1.02	1.29	1.23	.69	....	.98	.99

Treatment A consisted in heating the bars to 1000° C., which took 1 hour 25 minutes, holding them there for 25 minutes and cooling them in air. In treatment B, the bars were packed in a wrought iron tube, placed in an annealing furnace at 500° C., and brought to 870°–880° in 5½ hours. They were held there for 3 hours and then slowly cooled. The times of the other heatings have been given in the experimental methods adopted.

In the steels subjected to treatment B, the cementite was found* to have a composition represented by the formula $Fe(Ni)_3C$. Its analysis was:

Carbon, per cent.	6.25
Nickel, per cent.	1.86
Iron, per cent.	91.71

MECHANICAL.

The bars were turned down to a diameter of 0.564 inches, giving an area of 0.25 square inches, for a length of 2 inches.

The results are given in Tables IV to X, and also shown in Diagrams I and II.

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*G. B. Waterhouse. The Influence of Nickel and Carbon on Iron. *Journal Iron and Steel Institute*, No. II, 1905, p. 376.

TABLE IV.—Steel K. C. C. .41 per cent.; Ni 3.79 per cent.

Treatment.	Elastic Limit.	Ultimate Stress.	Elongation per cent. on 2 in.	Reduction of Area per cent.	Fracture.
	lb. per sq. in.	lb. per sq. in.			
Treatment A	48563	90246	26.0	44.7	Half cup and cone. Gray granular.
Heated 1000°	.....	71800	26.0	48.2	Half cup and cone. Gray granular.
Heated 1100°	44880	71700	25.5	48.6	Half cup and cone. Gray granular.
Heated 1200°	.....	74000	11.0	10.5	Crystalline, level fracture.
Heated 1300°	.....	71320	7.0	4.8	Coarsely crystalline.
1200° reheated 700°	38809	71487	10.5	10.4	Slightly finer than 1200°.
1200° reheated 775°	43515	74989	25.0	32.5	Gray granular, almost complete cup and cone.

TABLE V.—Steel L. C. C. .51 per cent.; Ni 3.79 per cent.

Treatment.	Elastic Limit.	Ultimate Stress.	Elongation per cent. on 2 in.	Reduction of Area per cent.	Fracture.
	lb. per sq. in.	lb. per sq. in.			
Treatment A	50469	99109	21.0	39.05	Half cup and cone. Gray granular.
Heated 1000°	.....	78600	25.0	42.5	Half cup and cone. Gray granular.
Heated 1100°	46600	78800	24.0	42.4	Half cup and cone. Gray granular.
Heated 1200°	47200	84900	11.5	12.1	Crystalline, level fracture.
Heated 1300°	.....	79600	5.0	5.2	Coarsely crystalline.
1200° reheated 700°	46805	81487	15.5	17.9	Crystalline, finer than 1200°.
1200° reheated 775°	47909	80795	22.5	33.1	Gray granular, deeply pitted.

TABLE VI.—Steel M. C. C. .63 per cent.; Ni 3.76 per cent.

Treatment.	Elastic Limit.	Ultimate Stress.	Elongation per cent. on 2 in.	Reduction of Area per cent.	Fracture.
	lb. per sq. in.	lb. per sq. in.			
Treatment A	56041	115421	16.5	26.3	Finely crystalline.
Heated 1000°	47200	89000	20.5	33.1	Gray granular, serrated edges.
Heated 1100°	47200	89400	19.0	32.5	Gray granular, serrated edges.
Heated 1200°	.....	99600	7.0	6.3	Crystalline, level fracture.
Heated 1300°	.....	85200	2.0	1.7	Coarsely crystalline.
1200° reheated 700°	.....	96040	10.0	10.8	Crystalline, level fracture.
1200° reheated 775°	53824	89842	21.0	34.5	Gray granular. Half cup and cone.

TABLE VII.—Steel N. C. C. .79 per cent.; Ni 3.81 per cent.

Treatment.	Elastic Limit.	Ultimate Stress.	Elongation per cent. on 2 in.	Reduction of Area per cent.	Fracture.
	lb. per sq. in.	lb. per sq. in.			
Treatment A	66850	135194	14.0	21.3	Finely crystalline, serrated edges.
Heated 1000°	.....	108960	15.0	23.5	Finely crystalline.
Heated 1100°	48000	111840	14.0	22.3	Finely crystalline.
Heated 1200°	.....	109600	3.0	3.1	Coarsely crystalline.
Heated 1300°	.....	66800	.5	1.0	Very coarsely crystalline.
1200° reheated 700°	.....	102705	6.0	9.5	Crystalline, finer than 1200°.
1200° reheated 775°	70276	99214	21.0	34.8	Mixture gray granular and fine crystals.

TABLE VIII.—Steel O. C. C. .97 per cent.; Ni 3.75 per cent.

Treatment.	Elastic Limit.	Ultimate Stress.	Elongation per cent of 2 in.	Reduction on Area per cent.	Fracture.
	lb. per sq. in.	lb. per sq. in.			
Treatment A	80120	156827	7.5	8.4	Fine crystalline, even surface.
Heated 1000°	114121	130336	Broke on shoulder		Fine crystalline, even surface.
Heated 1100°	107313	138112	3.5	4.2	Fine crystalline, even surface.
Heated 1200°	.....	83117	.5	.4	Coarsely crystalline.
Heated 1300°	.....	46648	.0	.3	Very coarsely crystalline.
1200° reheated 700°	66390	114107	5.5	6.3	Coarsely crystalline.
1200° reheated 775°	74437	103476	18.0	19.0	Fine crystalline, and level.

TABLE IX.—Steel Q. C. C. 1.24 per cent.; Ni 3.81 per cent.

Treatment.	Elastic Limit.	Ultimate Stress.	Elongation per cent. of 2 in.	Reduction of Area per cent.	Fracture.
	lb. per sq. in.	lb. per sq. in.			
Treatment A	102030	168697	3.5	3.2	Fine crystalline, very level.
Heated 1000°	70538	97510	15.0	17.9	Mixture gray granular, and fine crystalline, deeply pitted.
Heated 1100°	57982	98183	1.0	.4	Crystalline, level fracture.
Heated 1200°	.....	90729	.5	.0	Crystalline, platy fracture.
Heated 1300°	.....	60600	.0	.0	Crystalline, platy fracture.
1200° reheated 700°	69202	95103	1.5	1.0	Crystalline and level, Similar to 1100°.
1200° reheated 775°	74000	106304	3.5	5.3	Fine crystalline, and level.

TABLE X.—Steel R. C. C. 1.48 per cent.; Ni 3.82 per cent.

Treatment.	Elastic Limit.	Ultimate Stress.	Elongation per cent. on 2 in.	Reduction of Area per cent.	Fracture.
	lb. per sq. in.	lb. per sq. in.			
Treatment A	65530	145642	10.5	13.9	Crystalline, tinged with gray.
Heate l 1000°	35771	63950	23.6	37.6	Deep gray granular. Half cup and cone.
Heated 1100°	40320	66640	25.0	33.5	Deep gray granular, Pitted surface
Heated 1200°	47157	97894	8.0	5.0	Crystalline, level fracture.
Heated 1300°	.....	35480	1.0	.4	Crystalline, platy fracture.
1200° reheated 700°.	.....	89045	17.5	12.2	Deep gray, pitted surface.
1200° reheated 775°.	45967	74593	24.0	33.5	Deep gray, half cup and cone pitted surface.

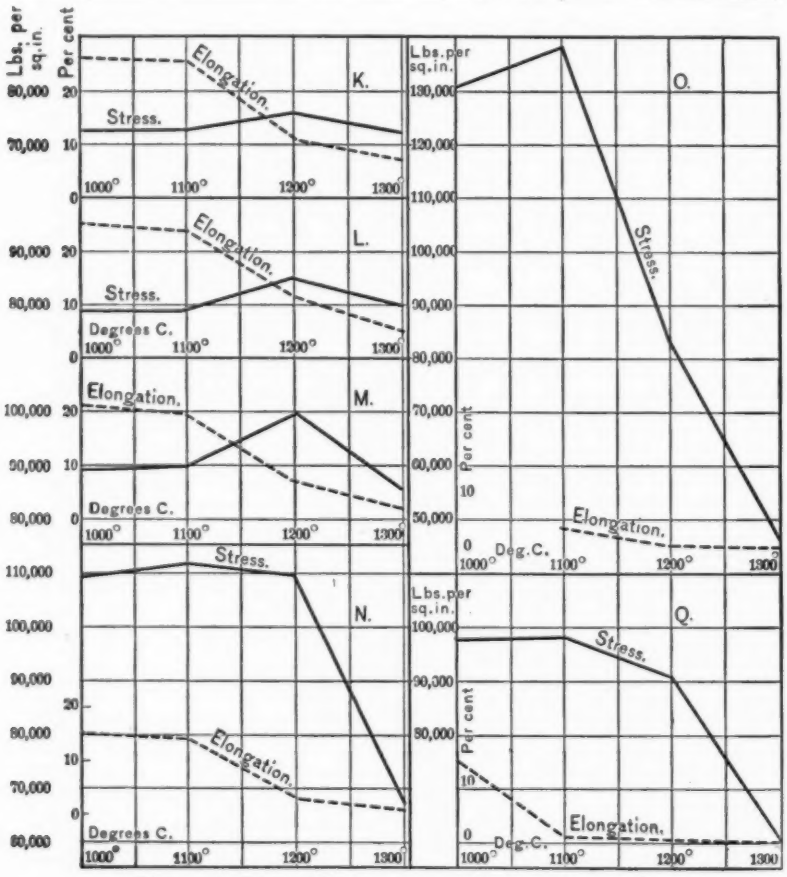

Diagram I. Effect of Overheating on Ultimate Stress and Elongation.

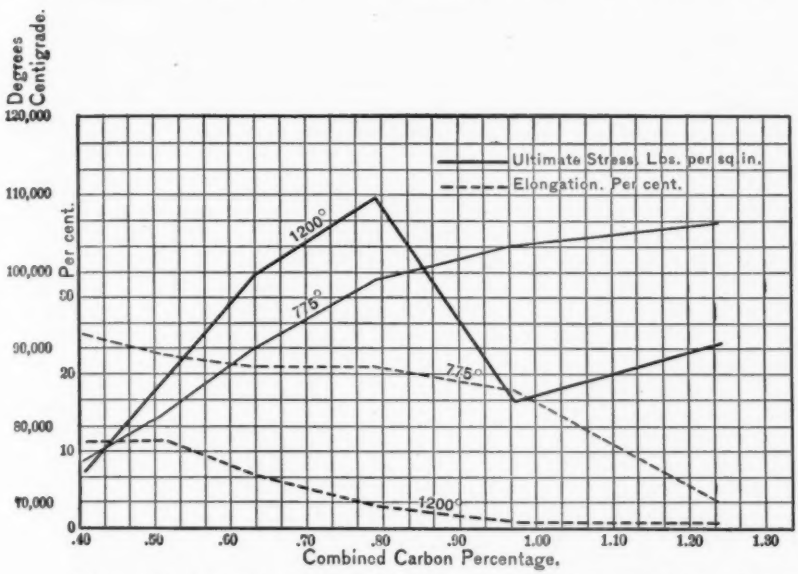

Diagram II. Comparison of Overheating at 1200°, and Subsequent Reheating to 775°

The growth of the crystals with increasing temperature, and the restoring by subsequent reheating is shown by Photograph I, which represents the fractures of O, the tests of which are given in Table VIII.

MICROSCOPICAL.

Transverse sections were taken of the bars after the various treatments. They were rubbed down on four emery papers of successively finer surface, and finally polished with wet rouge.

The constituents are ferrite, pearlite, cementite, and temper-graphite. Considering, first, the steels submitted to Treatment A; the first one, K, shows ferrite and pearlite in about equal amounts, micrograph 1. With increasing carbon the ferrite diminishes, micrograph 6. In the case of O, it forms the entire field, and Q, with 1.24 per cent. C. C. shows much free cementite, micrograph 10. In R, temper-graphite has separated, shown in micrograph 12, which is from the unetched section; when etched it shows the four constituents present at once, micrograph 13.

The steels heated to 1000° and 1100° are very similar. In the cases of K, L, M, and N, the pearlite has separated, and the

constituents are ferrite and cementite, the cementite increasing in amount with rise in carbon; micrograph 3. O, shows well laminated pearlite, and free cementite, micrograph 7. R, micrograph 14, shows temper-graphite, ferrite and cementite; and Q, after heating to 1000°, has a similar structure, but with less graphite.

On heating to 1200° and 1300° there is a marked change of structure, particularly in the cases of K, L, M, and N. The constituents are ferrite and pearlite, arranged in a lattice-work structure, with sharp lines of division; micrographs 2 and 5. O still shows pearlite and cementite, but the crystals have greatly increased, and have straight boundaries; micrograph 8. With Q the cementite increases in amount, and occurs plentifully within the pearlite crystals; micrograph 11. In the case of R, after heating to 1300°, all the carbon is combined, and is present as cementite; micrograph 15.

Reheating the overheated bars to 700° does not materially affect their structure.

Reheating to 775° restores the structure nearly to that found before overheating. K, L, M, and N are composed of ferrite and cementite, the cementite increasing in amount with the carbon; micrograph 4. O and Q show pearlite and cementite; micrograph 9; while R, once more has temper-graphite in a matrix of ferrite and cementite; micrograph 16.

CONSIDERATION OF RESULTS.

The effect of the different treatments on the condition of the carbon is full of interest. It would seem as if the rate of cooling had a powerful influence on the separation of the temper-graphite, for Treatment A, and the heating to 1000°, were taken to the same temperature, but cooled at different rates, giving very different results; 0.31 and 1.29 per cent. respectively in the case of R. (Table III.)

Heating to 1000°, followed by very slow cooling, effected the greatest separation of graphite. With increasing temperature less temper-graphite was formed; and after heating to 1300°, all the carbon was combined.

Examining the tables of the mechanical tests, and the dia-

grams, of the steels in which no temper-graphite separated, it is seen that the tests of the steels heated to 1000° and 1100° are very similar. This similarity is also noticed in the microscopical examination.

The marked change in structure seen in K, L, and M after heating to 1200°, is accompanied by an increase in ultimate stress, and a drop in ductility. Heating still further brings about a very coarse crystallization in all cases, an almost complete loss of ductility, and a great lowering in tenacity.

In the microscopical examination it is very noticeable how readily the pearlite of the lower members of the series separates into its constituents. The great change of structure brought about by overheating is therefore more easily recognized.

A change from a cellular to a similar lamellar banded structure was found by R. G. Morse,* when working on a .34 per cent. carbon steel. This great change in structure together with the abrupt change seen in the mechanical tests and fractures on passing from 1100° to 1200° would indicate the presence of some critical point, above which the injurious effects of overheating are very marked. Professor E. Heyn† noticed a similar result, when working on basic open hearth boiler plate steel of .07 per cent. carbon.

The results show that the nickel steels worked on, follow the same laws as ordinary steels with regard to structure and temperature. Among the most important of these are:—(1) The normal crystal size increases with the temperature and (2) The crystal size, even after slow cooling is proportional to the highest temperature reached.

For a full discussion of the laws governing the relation between structure and temperature reference may be made to Professor Howe's recent book.‡

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* R. G. Morse. Effect of Heat Treatment upon the Physical Properties and Microstructure of a Medium Carbon Steel. *Transactions American Institute Mining Engineers*, Vol. 29, 1899, p. 729.

† E. Heyn. The Overheating of Mild Steel. *Journal Iron and Steel Institute*, No. II, 1902, p. 73.

‡ H. M. Howe. Iron, Steel, and Other Alloys.

CONCLUSIONS.

The following conclusions may be drawn from the results:—

1. Steels with a low percentage of nickel follow the same laws regarding structure and temperature as ordinary steels.

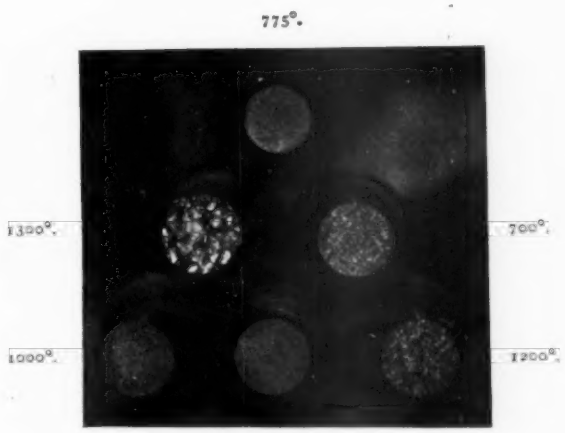
2. With the steels up to about 0.80 per cent. carbon, there is a critical point, between 1100° and 1200°, above which the injurious effects of overheating are very marked.

3. In the lower carbon steels overheating brings about a distinct type of structure; ferrite and pearlite arranged in a lattice work, with sharp lines of division.

4. In the higher carbon steels temper-graphite is most liable to be formed by heating to about 1000° followed by slow cooling.

5. With increasing temperature the temper-graphite goes back into combination.

PLATE XIV.
PROC. AM. SOC. TEST. MATS.
VOLUME VI.
WATERHOUSE ON BURNING AND OVERHEATING OF STEEL.



Fractures of O.

Micrograph 1. K. Treatment A. 225.

Micrograph 2. K. 1200°. 94.

Micrograph 3. L. 1000°. 260.

Micrograph 4. K. 1200° then 77.5620°

Micrograph 5. L. 1300°. 94.

Micrograph 6. M. Treatment A. 225.

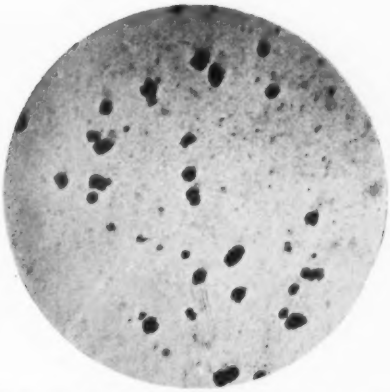
Micrograph 7. O. 1000°. 260.

Micrograph 8. O. 1200°. 260

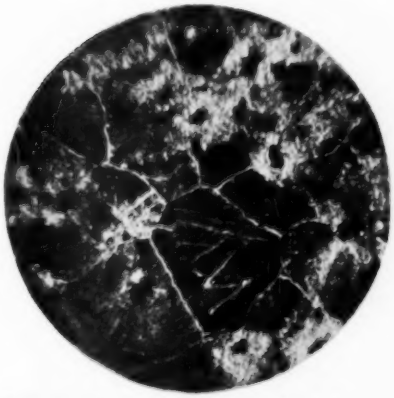
Micrograph 9. O. 1200° then 775°. 260.

Micrograph 10. Q. Treatment A. 260.

Micrograph 11. Q. 1200°. 260.

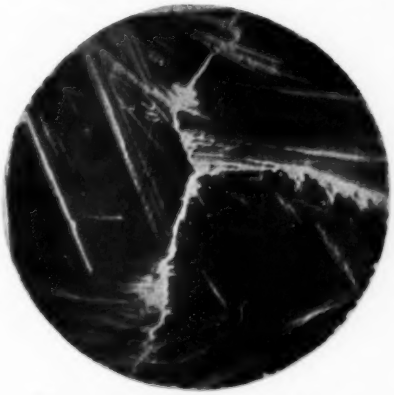


Micrograph 12. R. Treatment A. 260. Polished.



Micrograph 13. R. Treatment A. 340.

Micrograph 14. R. 1000°. 260.



Micrograph 15. R. 1300°. 260.

Micrograph 16. R. 1200° then 775°. 260

THE BENEFICIAL EFFECTS OF ADDING HIGH GRADE FERRO-SILICON TO CAST IRON.

By Alexander E. Outerbridge, Jr.

The conjurer's familiar trick of pouring a number of different liquids, such as milk and water (not combined), red ink, black ink, claret and sometimes even stronger liquids, from one bottle in any order named by his audience, is a never-failing wonder and surprise to juveniles and even to children of larger growth.

A less sensational, but far more practical, problem has long engaged the attention of metallurgists, viz: how to economically obtain from one cupola, in one heat, a variety of grades of molten iron suitable for different kinds of castings ranging, let us suppose, from those requiring high chilling iron such as chilled cast iron car wheels, or, from castings of high tensile and transverse strength, to small castings requiring extreme softness and ductility, in which great strength is not looked for. The wide variations in physical properties of cast iron are due to two combined causes, chemical composition and rate of cooling from the liquid state. Strength and softness are antagonistic qualities rarely found united.

Good car wheel iron is a strong metal containing less than one per cent. of silicon, having nearly one-half of its carbon chemically combined. Stove plate iron is a weak metal containing about three per cent. of silicon and very little, if any, combined carbon. Car wheel iron would be entirely unsuitable for stove plates, while stove plate iron would be useless for car wheels. Again, the metal which would be adapted to cast iron turn tables for large locomotives, or the iron intended for bed plates of heavy machinery and the like would not be suitable for either of the foregoing purposes.

It is the universal custom, therefore, to pour car wheels from special mixtures having suitable chilling properties, and stove plates from entirely different mixtures in different cupolas, which have but little chilling properties; but the modern metallurgist or general practitioner is daily called upon to provide

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Note.—This paper was contributed jointly and simultaneously to the American Society for Testing Materials and the American Foundrymen's Association.—A. E. O., Jr.

metal melted in one cupola and one heat, suitable for a great variety of castings and requiring, if the best results are desired, wide variations in physical properties as well as chemical constituents. The method adopted by the author many years ago and which is, no doubt, practiced by others to meet these varying requirements in a thoroughly practical manner, has been to group all the small work for the day, needing soft ductile iron, so that it will be cast at the beginning, or near the beginning, of the run of iron from the cupola, which is, of course, charged with the required amount of the softest grades of iron; the proportion of silicon in such mixtures approximating 2.5 per cent. This is followed by a medium grade of iron, calculated to contain about 1.9 per cent. silicon, giving a product suitable for miscellaneous castings of medium weight and thickness, and capable of being machined readily, but not too soft to give good wearing service; this, again, is followed by strong iron mixtures intended for large and heavy work requiring close-grained texture and usually high tensile and transverse strength. The strong iron may have as little as one-half of one per cent. of silicon and may possess a high chilling property. The transverse strength of the soft iron (2.5 per cent. silicon) when cast in bars one inch square section and fifteen inches long, broken in the middle with supports 12 inches apart, ranges from about 1,900 pounds to about 2,200 pounds and the tensile strength per square inch of the same bars, when turned and pulled on a machine, having automatically adjusted grips to insure a perfectly straight pull while the piece is being strained, averages ten times the transverse stress, or, 19,000 to 22,000 pounds per square inch.

The medium iron (1.9 per cent. silicon) averages 2,500 pounds transverse strength and 25,000 pounds tensile strength per square inch cast in the same size bars and tested under the same conditions. The strong iron should exceed 3,000 pounds transverse strength and 30,000 pounds tensile strength of the same bars in the regular daily work.

"Special castings" have been made in the foundry of William Sellers and Co., Incorporated, (where the author has been engaged for nearly twenty years as metallurgist), which have united the two antagonistic properties of high tensile strength with softness and ductility in a remarkable degree. Tensile tests of bars .5 inch square section (being the same thickness as the castings) formed

in the same mold with the castings and attached thereto, have shown, when turned and pulled on a 100,000-pound Emery hydraulic testing machine, extraordinary tensile strength, viz: 40,535 pounds to 44,565 pounds per square inch. These are believed to be the highest records ever noted for soft cast iron, if indeed they are not the highest for any kind of cast iron melted in a cupola.

It is of course impracticable to obtain a perfectly sharp dividing line between the soft iron, medium iron, and strong iron charged in a cupola and in the molten metal withdrawn therefrom, for it is impossible to prevent a portion of the product, if the composition is varied during the charging of the cupola from being to a certain degree variable, so as not to be accurately predictable as to its composition and physical properties in individual taps at the time when the metal is tapering off from one grade to another.

To overcome this uncertainty it is customary, in the foundry already named, to arrange the daily work so as to have a certain number of castings serve as "buffers," i. e., to take iron that is intermediate between the different grades charged in the furnace, and this method has proved very satisfactory. The buffers are usually castings that require but little machining and in which a considerable variation of composition of the metal is permissible. There are always plenty of such castings made in every foundry each day.

To supplement this routine method by a simple and cheap process of varying the chemical constituents and physical properties of molten iron after it has been tapped from the cupola and removed from the source of heat, is a desideratum devoutly to be wished for, and many efforts have been made to perform the trick. The prime difficulty is found in the fact that the melting point of cast iron is lower than that of nearly all of the metals or metalloids that are suitable for the purpose. For example, the addition of wrought iron or steel to cast iron increases its strength and chilling properties. It is a common practice to add steel in the cupola for this purpose, but, if the attempt be made to incorporate steel or wrought iron in the form of chips or small pieces in a ladle of molten iron withdrawn from the source of heat supply, it will be found unsatisfactory for the reason that the melting point of steel is too high to permit a sufficient amount of it to be dissolved in and diffused throughout

the molten iron to effect a radical change in physical property without causing dull iron to result therefrom.

The element silicon is practically the governor that determines the degree of hardness of cast iron, therefore the value of a single and inexpensive process that would enable the intelligent founder to control the proportion of silicon in any individual ladle of molten iron drawn from the melting furnace would be at once apparent, especially in foundries where miscellaneous castings, ranging in size from small pulleys, with rims one-quarter inch thick, to bed plates for various machines, hydraulic cylinders and the like, sometimes weighing many tons and of various thickness, up to a foot or more in thickness, as is the daily practice in many foundries.

In the year 1886 the author made many experiments in this direction, using the richest grades of ferro-silicon then obtainable, containing from 10 per cent. up to 18 per cent. of silicon, by adding the alloy in small lumps or in powder to ladles of molten iron, but found that the metal would not dissolve a sufficient quantity of the alloy to greatly change the proportion of silicon and thus to produce a marked increase in softness of the iron without appreciably affecting the temperature and fluidity of the molten iron. Preheating the alloy was the next logical step tried with an improved result, but it was soon ascertained that the inconvenience and cost of heating the alloy red hot would militate against its general usefulness. At the same time it was found that the addition of a small amount of ferro-manganese containing 80 per cent. manganese (then a commerical product) accomplished the object sought in car wheel mixtures in a totally different manner by changing the condition of the carbon and without the necessity of heating the alloy. Therefore the tests with ferro-silicon were discontinued. In recent years electro-metallurgy has made giant strides and it is now possible to obtain commercially pure silicon (over 98 per cent. pure) and ferro-silicon alloys of extreme richness ranging from 50 to 80 per cent. silicon or over. This fact caused the author to again take up the experiments of adding silicon to ladles of molten cast iron where he had left off in 1886. A quantity of 98 per cent. silicon, made in an electric furnace at Niagara Falls, was obtained in large lumps. This material resembles in appearance 80 per cent. ferro-manganese but is very much lighter in weight, bulk for bulk, the specific gravity being about one-third

that of 80 per cent. ferro-manganese and less than one-third that of cast iron. Many tests were made with this new material which resulted in failure, owing partly, no doubt, to the very high melting point of silicon (about the same as steel) and partly to its levity which caused the powder to float to the surface of the molten iron if sprinkled into the ladle, or to simply cake if fastened to the bottom. When an alloy of silicon and iron containing 50 per cent. of silicon was used, however, a very different result was noted. This material was obtained in the form of coarse powder and was sprinkled into the molten iron as it was tapped into the ladle. Instantly the surface of the molten iron became "alive," as the workmen aptly expressed it; a rapid circulation of the skin of oxide which always forms on the surface was noticed, moving in circles like ripples from the center toward the edge of the ladle, this lively movement continued until the metal was poured and the same movement was noticed in the gates and risers of the castings. The usual test bars were poured both from the treated metal and from the same iron untreated. "Chill test pieces" were also poured into heavy iron cups, which serve by the extremely rapid cooling of the small chill test bars to magnify any chilling property just as a miscroscope magnifies any minute object. Few practical founders are aware of the fact that there is a very great difference in the chilling property of soft foundry irons, as the metal if poured in a sand mold, even in very thin section, does not show an appreciable chill, yet it does show the effect of such concealed chill under the machining operations of drilling, planing or milling, for the reason that particles of iron containing combined carbon may under such conditions be distributed throughout the castings, which are too minute to be seen by the naked eye, but destroy the cutting tools. The chill cup test is in effect a physical analysis of practical value which enables the foundry foreman to know the character of every ladle of iron, small or large, before he pours his metal. The little tapered bars poured in the cups, which become solidified immediately, are then turned out, cooled in a bucket of water and broken. Such tests are poured from every tap, broken at once and placed in a row for the foreman's inspection.

The chill cup tests of the treated and untreated iron in the foregoing experiment showed at once that the small amount of 50 per cent. ferro-silicon added, viz: half a pound in a 200-pound

ladle, had dissolved in the iron wiping out the chill in the metal almost completely. The regular transverse test bars when broken showed two very interesting features, one of which was anticipated, the other unexpected. The metal of the treated bars was much softer in appearance as was already indicated by the chill cup tests, but, instead of being weaker, the treated bars were *all stronger than the untreated bars*. In other words, increased softness and increased strength (two usually antagonistic properties) were here combined. The castings poured from the treated metal were small pulleys having rims about ¼-inch thick that are ordinarily turned at a speed of 25 feet a minute. The treated pulleys were turned without destroying the cutting edge of the tool at 40 feet per minute as shown by memoranda furnished by the lathe operator.

The sucess of these initial tests led at once to more extended investigations, all corroborating the correctness of the first observations. Analysis showed that the actual increase in silicon was slightly less than the calculated increase, and further tests showed that there is a limit to the amount of the alloy that can be incorporated, depending upon the initial heat of the iron and the size of the ladle.

Another interesting observation is that a given increase of silicon, say one quarter of one per cent., imparted to molten iron in this manner is more effective as a softener than an equal increase of silicon imparted through the cupola in the charging of the iron, while any increase of silicon in the cupola always causes a corresponding decrease in strength of the metal. The rationale of the increase in strength with increased softness discovered in these tests is, in all probability, to be found in the deoxidation of the iron by the silicon added in its nascent condition. It is now quite generally believed that there is a small amount of oxide of iron dissolved in all iron melted in a cupola (notwithstanding the high percentage of free carbon) and that this oxide is a weakening element. Silicon has a strong affinity for oxygen and presumably seizes upon the oxgyen of the dissolved iron oxide, liberating the iron, the silica (oxide of silicon) thus formed having specific gravity of only 2.41 as compared with 7.15, the sp. gr. of cast iron, rises to the top, thus accounting for the two facts herein noted, viz: the rapid circulation of the skin on the surface of the molten

iron in the ladle, and the apparent slight loss of silicon when added in the alloy. The reason why an alloy of iron and silicon, rich in the latter element, dissolves and diffuses throughout the molten mass, while pure silicon will not, is probably owing partly to its relatively high specific gravity (over 6) and partly to the fact of already being alloyed with iron which melts and acts as a diffusing vehicle enabling the silicon to become incorporated with the molten iron. The action is very similar in this respect to that of manganese in the 80 per cent. ferro-manganese already spoken of.

Not desiring to extend this paper to undue length, details of many similar tests are omitted which, it may be said, have resulted in the practical adoption of this method of treating iron in the ladle in the foundry of Wm. Sellers and Co., Incorporated, as a ready and reliable means of producing very soft and at the same time strong iron for small castings from metal of medium grade which would not otherwise be so well adapted for the purpose.

The 50 per cent. powdered ferro-silicon used costs about four cents per pound at the present time, but, as the quantity required to produce the desired result is so small, viz: about half a pound, or less, to a hundred pounds of iron, the cost is really trifling, and is far more than counterbalanced by the fact that cheaper grades of pig iron may be used in the furnace. Added to this is the great practical value of being thus able to control the product absolutely and to vary the character of the metal in regard to softness, or machining quality, while at the same time increasing the strength and ductility of individual ladles of molten iron drawn from one common source.

The author's experiments in adding 80 per cent. ferro-manganese to car-wheel iron in ladles in the year 1886 briefly alluded to have have been thoroughly exploited years ago in technical journals and have been frequently mentioned by other writers. The process has come into large daily use and as its merits and limitations are familiar to all car-wheel makers and most metallurgists it is not considered necessary to refer at length to the subject in this place.

Appended hereto is a table of a few tests of treated and untreated bars of soft and medium grades of iron all showing gains in strength ranging from 2.3 per cent. to 26.5 per cent., and in deflection of the bars from 7.14 to 31 per cent., while the increase

in softness was very marked indeed. It is hoped that these few records may prove interesting and valuable to founders.

RESULTS OF TESTS OF FERRO-SILICON IN LADLES.

Date.	Ferro-Silicon added.	Breaking Strain (pounds).	Deflection (inches).	Resilience.	Shrinkage (inches).	Per cent. Gain.		
						Breaking Strain.	Deflection.	Resilience.
Oct. 10, '05	½ lb Hand	*A 2265	.120	45.30	.192	Per cent.	Per cent.	Per cent
	Ladle	B 2155	.112	40.09	.191			
	Gain	110	.008	5.21		5.1	7.14	13.
Oct. 11, '05	½ lb Hand	A 2215	.137	50.51	.182			
	Ladle	B 2165	.124	44.60	.185			
	Gain	50	.013	5.91		2.3	10.4	13.2
Oct. 14, '05	½ lb Hand	A 2600	.152	65.79	.196			
	Ladle	B 2055	.116	39.18	.188			
	Gain	545	.036	26.61		26.5	31.	67.
Oct. 15, '05	½ lb Hand	A 2330	.143	55.45	.183			
	Ladle	B 1893	.110	34.60	.183			
	Gain	437	.033	20.85		23.8	30.	60.2
Oct. 16, '05	½ lb Hand	A 2210	.124	45.54	.183			
	Ladle	B 2120	.112	39.44	.185			
	Gain	90	.012	6.10		4.2	10.7	15.4
Nov. 13, '05	1 lb 200 lb	A 2370	.139	54.76	.186			
	Ladle	B 2050	.118	40.19	.184			
	Gain	320	.021	14.57		15.6	17.8	36.2
Nov. 21, '05	1 lb 200 lb	A 2178	.128	46.34	.188			
	Ladle	B 2000	.119	39.60	.182			
	Gain	178	.009	6.74		8.9	7.5	17.

* A, Treated metal; B, same iron untreated.

TENSION-TESTS OF STEEL ANGLES.

By Frank P. McKibben.

The tension-tests which form the subject of this paper were made in the testing laboratory of the Massachusetts Institute of Technology upon twenty-seven specimens of rolled steel angles such as are used for tension members in riveted structural work. They were made with a view of studying the following points:

1. The ultimate strength of the angles in tension.
2. The value of a lug in transmitting stress from the outstanding leg of the main angle into the hitch plate.
3. The relative strength of angles where the gauge line for rivets and where the center of gravity line, respectively, pass through the center of the pull.
4. The relative strength of single angles and angles riveted together to form pairs.

There are three specimens of each of nine different types, making in all twenty-seven specimens. These are shown in detail in Fig. 1. Each of the main angles, 5 ft. 4 in. in length, is riveted at each end to a hitch plate.

Types A_1, B_1, and C_1 consist each of one angle, $3\frac{1}{2} \times 3 \times \frac{3}{8}$ in., $4 \times 3 \times \frac{3}{8}$ in., and $6 \times 4 \times \frac{3}{8}$ in. respectively, riveted to the hitch plates by one leg only.

Types A_2, B_2, and C_2 consist each of one angle of the same size as A_1, B_1, and C_1 respectively, and have both legs connected to the hitch plates; the outstanding leg being connected by means of a lug angle.

Types D_1 and D_2 each is made up of two $3 \times 3 \times \frac{5}{16}$ in. angles, one on either side of the hitch plate. D_1 is not, and D_2 is provided with lugs for each of the outstanding legs of the main angles.

In each of the types just mentioned the gauge line for rivets in the main angle is run through the center line of pull. In the case of angles with unequal legs the long leg is placed in contact with the hitch plates.

Type B_3 consists of one $4 \times 3 \times \frac{3}{8}$ in. angle connected to the

Acknowledgment is made to the *Engineering News* for the cuts used in this paper.—Ed.

hitch plates by one leg only. It differs from type B_1 in that the line of pull coincides with a projection of the center of gravity line instead of with the gauge line for rivets.

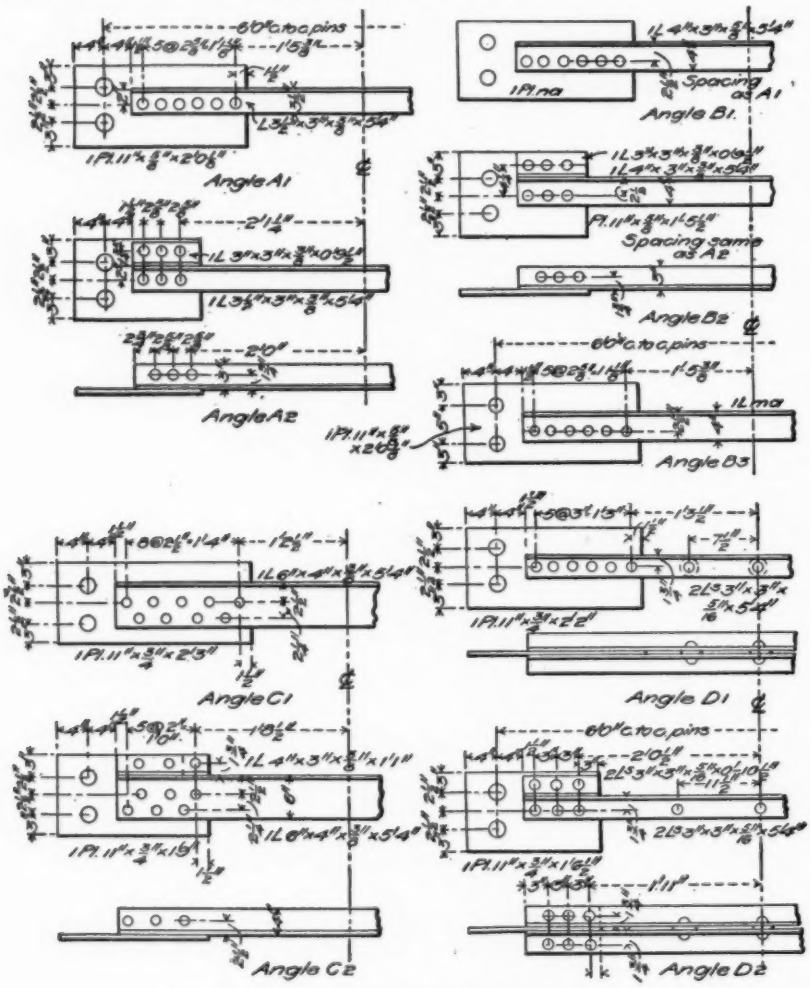


FIG. 1.—Specimens for Tension Angle Tests.

The end connections were designed to insure failure in the main angles, and the specimens were made as long as could be tested conveniently. The hitch plate at each end of each speci-

men was provided with two 2-in. holes, by means of which it was pinned between two holding plates fastened in turn by a single pin to a third plate gripped by the testing machine. A diagram of this holding device is shown in Fig. 2.

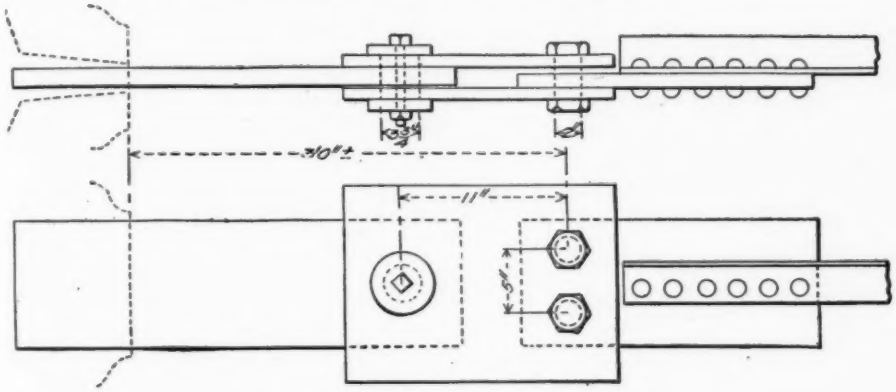


FIG. 2.—Device for Holding Test Angles.

All of the pieces of angles of a given size were cut from one long angle, and from each of these long pieces there were also made two small tensile test specimens. Table I gives the average results of the tensile tests on the small specimens which were approximately 18 x $1\frac{1}{2}$ x $\frac{3}{8}$ or $\frac{5}{16}$ in. in size.

TABLE I.

TENSILE STRENGTH OF SMALL TEST SPECIMENS CUT FROM STEEL ANGLES.

Size of Angle from which Specimen was Cut.	$3\frac{1}{2}$ x 3 x $\frac{3}{8}$ in.	4 x 3 x $\frac{3}{8}$ in.	6 x 4 x $\frac{3}{8}$ in.	3 x 3 x $\frac{5}{16}$ in.
Yield Point.....	33160	31600	32600	34800
Ultimate Strength ...	59300	54000	51600	61000
Per cent. Elongation in 8 in.	28.0	28.6	31.1	29.5
Per cent. Reduction of Area.....	48.9	54.6	56.5	52.6
Fracture	Silky	Silky	Silky	Silky

Fig. 3 shows diagrammatically the outlines of the various fractures, all of which occurred in the main angles. There was no

failure of rivets. The numbers on the sketches show the sequence of the fractures. With the exception of one of the specimens, made of two $3 \times 3 \times 1\frac{5}{16}$ in. angles, failure took place at one of the inner rivets which connects the angle to the hitch plate, that is, the connecting rivet which lies nearest the center of the specimen. In the case of the exception noted, rupture occurred at the center of the specimen where there is a single rivet connecting the two angles together. In all cases just before failure the metal between the inner rivet and the outer edge of the leg connected by that rivet to the hitch plate, drew down considerably at both ends of the specimen. Failure then occurred at this

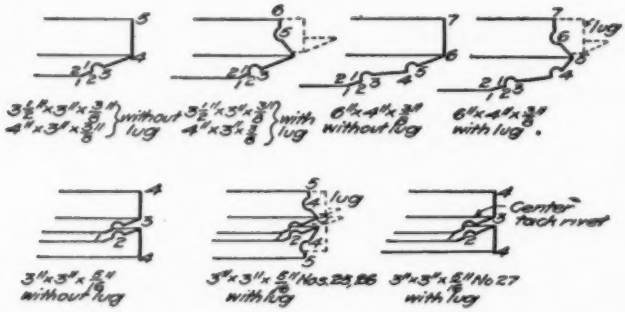


Fig. 3.—Sketches of Fractures of Steel Angles.

point, continuing slowly across the horizontal leg and then up the vertical leg. With the one exception cited, failure occurred, in all specimens having lugs, on a zigzag section, passing through rivets in the horizontal and in the vertical legs. In order to secure the greatest strength from an angle in tension this zigzag section should be equal to or greater than the net right section. In none of the specimens tested is this the case. Consequently the total ultimate strength of some of the specimens with lugs is less than that of similar specimens without the lugs. However, the strength per square inch of net area is greater where the lugs are provided, showing that with the proper spacing of rivets to utilize the maximum net area the lug is an advantage.

Table II shows in detail the results of the tests.

TABLE II.

SUMMARY OF TENSION-TESTS ON STEEL ANGLES.

Type.	No. of Specimens.	Nominal Size.	Cross Section. Area in Square Inches.			Breaking Load. Lbs.		Per Cent. Strength of Material Developed.*	Remarks.
			Nominal.	Actual Gross.	Net.	Total.	Per Sq. Inch of Net Area.		
A_1	1	$3\frac{1}{2} \times 3 \times \frac{1}{2}$	2.30	2.29	1.95	89,500	45,900	77.4	Without lugs.
"	2	"	"	2.32	1.98	96,100	48,500	81.8	
"	3	"	"	2.35	2.00	95,200	47,600	80.2	
"	Mean		"	2.32	1.98	93,600	47,400	79.8	
A_2	4	$3\frac{1}{2} \times 3 \times \frac{1}{2}$	"	2.28	1.78	84,600	47,500	80.1	With lugs.
"	5	"	"	2.28	1.78	88,600	49,800	84.0	
"	6	"	"	2.27	1.77	91,200	51,500	86.8	
"	Mean		"	2.28	1.78	88,100	49,600	83.6	
B_1	7	$4 \times 3 \times \frac{1}{2}$	2.49	2.44	2.10	85,000	40,500	75.0	Without lugs.
"	8	"	"	2.42	2.09	84,000	40,100	74.3	
"	9	"	"	2.50	2.15	85,600	39,800	73.7	
"	Mean		"	2.45	2.11	84,900	40,100	74.3	
B_2	10	$4 \times 3 \times \frac{1}{2}$	"	2.42	1.92	83,500	43,500	80.5	With lugs.
"	11	"	"	2.43	1.92	85,100	44,300	82.0	
"	12	"	"	2.45	1.95	84,100	43,100	79.9	
"	Mean		"	2.43	1.93	84,200	43,600	80.8	
B_3	13	$4 \times 3 \times \frac{7}{16}$	"	2.41	2.07	88,600	42,800	79.3	Center of gravity line through pull.
"	14	"	"	2.42	2.09	90,400	43,200	80.0	
"	15	"	"	2.41	2.07	91,000	44,000	81.4	
"	Mean		"	2.41	2.08	90,000	43,300	80.2	
C_1	16	$6 \times 4 \times \frac{1}{2}$	3.61	3.53	3.11	131,000	42,100	81.6	Without lugs.
"	17	"	"	3.54	3.12	125,700	40,300	78.1	
"	18	"	"	3.50	3.07	128,200	41,800	81.1	
"	Mean		"	3.52	3.10	128,300	41,400	80.3	
C_2	19	$6 \times 4 \times \frac{1}{2}$	"	3.50	3.04	131,500	43,300	84.0	With lugs.
"	20	"	"	3.50	3.03	130,200	42,900	83.2	
"	21	"	"	3.50	3.04	131,900	43,400	84.1	
"	Mean		"	3.50	3.04	131,200	43,200	83.7	
D_1	22	Two $3 \times \frac{5}{16}$	3.56	3.44	2.88	134,100	46,600	76.4	Without lugs.
"	23	"	"	3.43	2.87	136,500	47,700	78.3	
"	24	"	"	3.49	2.91	139,100	47,800	78.4	
"	Mean		"	3.45	2.89	136,600	47,400	77.7	
D_2	25	Two $3 \times \frac{5}{16}$	"	3.43	2.69	137,900	51,200	84.0	With lugs.
"	26	"	"	3.43	2.69	140,400	52,200	85.6	
"	27	"	"	3.42	2.86	138,800	48,500	79.6	
"	Mean		"	3.43	2.75	139,000	50,600	83.1	

* Figures of previous column compared with specimen tensile test results of Table I.

Table III shows the per cent. increase in the strength per square inch of net area due to the lugs.

TABLE III.

SHOWING VALUE OF LUGS.

Type.	Number of Specimen.	Ultimate Strength per Square Inch of Net Section.	Per Cent. Increase in Strength per Square Inch of Net Area.
A_1	1, 2, 3.	47400	.....
A_2	4, 5, 6.	49600	4.7
B_1	7, 8, 9.	40100	.....
B_2	10, 11, 12.	43600	8.7
C_1	16, 17, 18.	41400	.....
C_2	19, 20, 21.	43200	4.4
D_1	22, 23, 24.	47400	.....
D_2	25, 26, 27.	50600	6.8

The results of the tests show that the ultimate strength per square inch of net section for angles having gauge lines for rivets passing through the center of pull varies, for the single angles, from 39,800 to 51,500 pounds, which is approximately from 74 to 87 per cent. of the strength of the tensile test specimens; and for angles riveted together in pairs from 46,600 to 52,200 pounds, which is approximately from 77 to 86 per cent. of the strength of the material as developed by the tensile test specimens.

The efficiency of the lug is shown by the fact that for specimens provided with lugs there is an increase over specimens not so provided of from 4.7 to 8.7 per cent. in ultimate strength per square inch.

A study of the results of the $4 \times 3 \times \frac{3}{8}$ in. angles without lugs shows that there is a gain of 8 per cent. in the strength per square inch for specimens having the projection of the center of gravity line, instead of the gauge line for rivets, coinciding with the line of pull. It further appears that for these angles the strength per square inch is practically the same for those specimens having the center of gravity connections *without* lugs as it is for those having the gauge line connections *with* lugs.

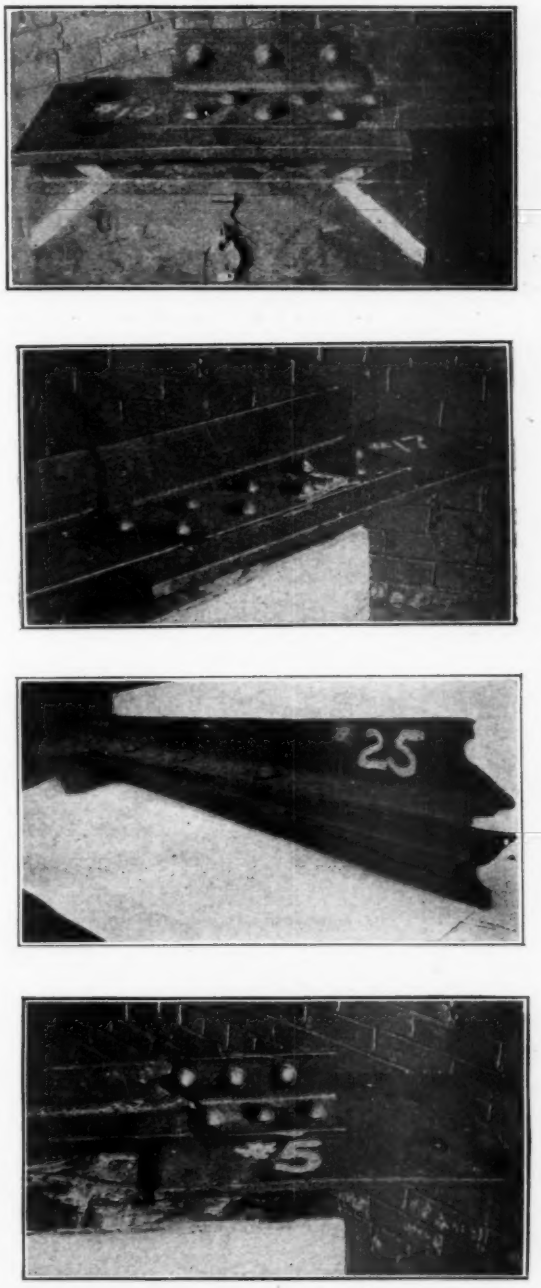


Fig. 4.—Photographs showing Fractured Angles.

Notwithstanding the fact that the net as well as the gross area of the two $3 \times 3 \times \frac{5}{16}$ in. angles is less than in any of the single $6 \times 4 \times \frac{3}{8}$ in. specimens, yet the ultimate load carried by the former is greater in every case. This is no doubt largely due to the greater strength of the material in the double specimens on account of their smaller size and thickness.

In closing, the writer wishes to express his obligations to Messrs. Arthur L. Davis and S. P. Waldron of the American Bridge Company for the specimens tested, and to Messrs. A. F. Holmes, instructor, and C. T. Bartlett and H. P. Orcutt, students in the Institute of Technology, who carefully did the work in the laboratory.

FIRE BOX STEEL—FAILURES AND SPECIFICATIONS.

By Max H. Wickhorst.

The author has for several years been giving considerable attention to the subject of care of locomotive boilers including study of failures of fire box sheets, and he hopes the following discussion on this subject may prove of some interest and usefulness.

In general, fire box sheets fail in one of two ways; first, gradual failure; the sheet may have a good many small cracks which are mostly in a vertical direction. These cracks are thickest radiating out from the stay bolts and frequently run from one stay bolt to another in the same vertical row, but never between stay bolts horizontally. These cracks are almost always on the fire side and at times extend through the thickness of the sheet first going through next to the stay bolts. Such sheets are almost always accompanied with more or less corrugation and the cracked and corrugated condition is almost always confined to the lower half of the sheet. Secondly, sudden failure, or rupture; the sheets may fail by a single crack or rupture from a foot to several feet long. In bad cases, the crack may extend from the mud ring to the crown sheet, but ordinarily, the crack is confined to the lower half of the sheet, extending upward from the mud ring or from a few inches above it, and is always near the middle of the side sheet longitudinally. Such sheets may show no corrugations and may show very little if any other defects. The failures of the first kind are of gradual formation, but those of the second class occur suddenly.

Conditions of Failures Classified.

About two years ago a lot of records and papers concerning failures of fire box sheets were gathered out of the files in the Superintendent of Motive Power's Office of the Chicago, Burlington and Quincy Railway Lines East of the Missouri River, and a classification made of the conditions under which

Acknowledgment is made to the *Engineering News* for the cuts used in this paper.—Ed.

the failures occurred, with results as shown below. These failures include only those occurring in class two mentioned above or ruptures.

	Number.	Per cent.
1. Washing—Cooling	3	7.7
2. " Using nozzles	16	41.0
3. " Filling	2	5.1
4. " After filling	7	17.9
5. In shop or house, cold	7	17.9
6. In house, hot	2	5.2
7. Discovered arriving at terminal	2	5.2

It will be noted from the above that 71.7 per cent. occurred while the engine was being washed, this including 41 per cent. where nozzles were being used at the time. 17.9 per cent. occurred while the engine was cold under other circumstances, making a total of 89.6 per cent. for the failures while the engine was cold, and thus leaving 10.4 per cent. for such failures while the engine was hot, but it is not improbable that if the full details were at hand of the conditions attending the failures in these latter cases, that in some or perhaps all, the records would show the engine had been cold. When washing the boilers, cold water had probably been used in all cases, and the above figures would seem to argue very strongly in favor of keeping the boiler continuously hot, and to use a method of washing out where the boiler does not get cold, say not below 150 degrees Fahrenheit.

TEMPERATURE TESTS OF FIRE BOX STEEL.

If the metal is at any time heated to a red heat or to near a red heat failure from this cause would be the natural result, and in order to get some information concerning the temperatures actually attained by locomotive fire box sheets, etc., under conditions of service, I arranged to get an electric pyrometer consisting of a platinum thermo-couple and galvanometer, and the intention was to work the boiler at rates similar to service conditions, and insert the junction of the thermo-couple through a small hole drilled in a stay bolt, extending across to near the fire side. Tests of this kind have not as yet been made, but some preliminary results have been made with the apparatus shown

herewith as Fig. 1. From this it will be seen that the method of test consists of boiling water in a can with thin sheet steel sides, with a bottom of half inch boiler plate, four inches in diameter brazed to the sides. The boiler plate has a hole drilled into the side one-eighth inch in diameter extending to the middle of the plate. Heat is supplied by a specially constructed "Pepper Box" burner which gives a lot of gas flames over a flat circular area of about four inches in diameter. The junction of the thermo-couple is inserted into the hole of the plate to the middle, and the temperature is read on a galvanometer. Some pre-

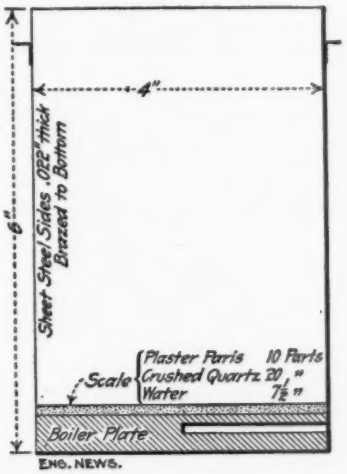


FIG. 1.—Temperature Tests of Fire Box Steel Apparatus.

liminary results are shown in Fig. 2, from which it will be noted that if a fire box sheet (including flue sheet) or the flues are free from scale or mud, the temperature of the metal probably does not at any time exceed the temperature of the water more than 50 degrees Fahrenheit, providing of course the circulation is sufficient to keep the water always in contact with the metal. Under the conditions of this experiment with no scale or water on the plate, the metal attained a temperature of about 1300 degrees Fahrenheit, and it will be noted from the diagram that with one-eighth inch scale the metal attained a temperature of about 200 degrees above the temperature of the water; with one-quarter inch something over 400 degrees.

In a locomotive fire box, the average temperature of the metal if not protected by the water, would probably run between 2000 and 3000 degrees Fahrenheit, and with scale one-eighth inch thick and with water in the boiler, the experiments indicate that the metal including fire box ends of the tubes, can readily attain a temperature of several hundred degrees above the temperature of the water, and it is not unlikely in some cases that the metal actually attains a low red heat.

MUD ACCUMULATIONS.

The action of the heat causes the water to flow upward between the tubes, and the counter current must flow down-

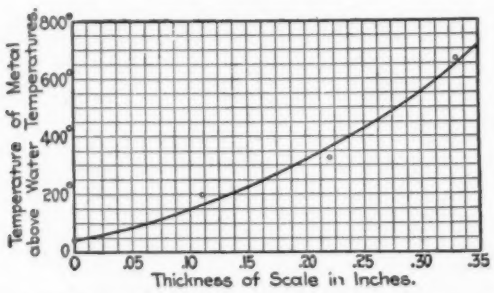


FIG. 2.—Temperature Tests of Fire Box Steel. Curve of Results.

ward between the tubes and shell of the boiler. The water evaporated from the side and other sheets of the fire box is probably supplied mostly by a current flowing backward along the bottom of the barrel of the boiler. When this current reaches the flue sheet it divides, half going to each side water leg, the current finally ending in the back water leg where the two side currents meet. Of course while this backward movement of the water is going on, the formation of steam also maintains an upward movement. This circulation carries all solid material that is light enough to move with the water, into the back water leg where the circulation is probably least rapid. The heavier particles of mud and very light scale deposit on the back mud ring up as high as the fire line which is about six inches above the mud ring. There is on the back mud ring a cubic foot or so of quiet water space into which the mud and lime

sludge is first carried, and when this space is filled up, deposits accumulate on the side mud ring and finally accumulations may occur on the front mud ring. Critical examination of the mud deposits in a boiler after the water is drawn out is apt to show very little if any mud on the front mud ring, and a depth of six or eight inches on the back mud ring with more or less mud on the sides. No mud is apt to be present in the barrel of the boiler, as determined by a view through an inspection hole in the back flue sheet under the flues. Where there are also scale deposits, these will be found mostly in the barrel of the boiler and on the front mud ring as scale is too heavy to be carried round by the circulation, but the mud deposits will be found about as I have described above. The usual scale and mud deposits are illustrated in Fig. 3. Up to a height of

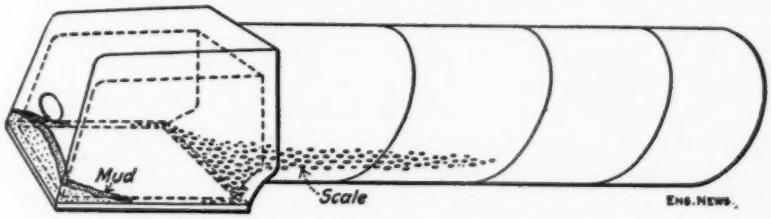


FIG. 3.—Mud and Scale Accumulations.

four or six inches above the mud ring, the mud accumulations remain below the fire line and cannot cause over-heating of the sheets, but if more mud is allowed to accumulate in a boiler, it cannot be taken care of in this space. Such excess mud makes more or less trouble by keeping in the water circulation, depositing quickly on the tubes, crown sheet and particularly in the side and back water legs as soon as active steam production stops, and in this way is apt to cause over-heating of the side and back fire box sheets by preventing free access of water.

If by means of a blow-off arrangement the back mud ring can be kept free from mud, it would seem clear from the above considerations that the boiler can be kept free from excessive mud accumulations since all the mud is carried by the circulation into the back mud ring. A blow-off in the middle of the back water leg right above the mud ring removes mud from where it tends to accumulate most, but experience has shown

the author that the mud is removed right around the blow-off cock, but on either side the accumulations are not disturbed. This led to trial of blow off pipe laying on the full length of the back mud ring and perforated with holes spaced about four or six inches apart. This arrangement has been tried somewhat extensively and experience shows that mud can by this means be thoroughly removed from the boiler without the necessity of cooling down the boiler and washing.

Where water is treated with soda ash, the function of the soda ash is to cause the lime and magnesia salts to come down

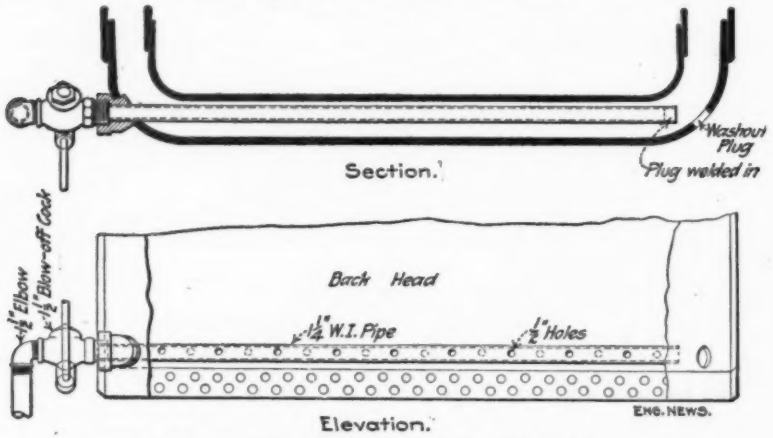


FIG. 4.—Blow-off Pipe in Back Water Leg.

as a sludge instead of adhering as scale, and the circulation then carries the sludge into the back water leg where it can be successfully removed through a perforated blow-off pipe placed on the back mud ring. By a combination of treatment of water with soda ash, the perforated blow-off pipe mentioned and system of blowing out at terminals, engines can be made to run regularly 5,000 miles between wash-outs and without change of water other than obtained by the blowing out at terminals. A perforated blow-off pipe arrangement suggested for general use is shown in Fig. 4.

TEMPERATURE TESTS OF INJECTED WATER.

The water supplied into the boiler by means of an injector has a temperature ranging from 150 to 180 degrees Fahrenheit,

while the water in the boiler has a temperature with modern engines not much below 400 degrees Fahrenheit. Where water is injected into the boiler through an ordinary check valve placed on each side, this water drops to the bottom of the boiler unless there is active steam production going on to promote circulation.

If an engine is standing still, as for instance, at a station and the injector is on, the injected water seeks the lowest part of the boiler which would be the water legs around the fire-box. In order to know what was the extent of the segregation of such

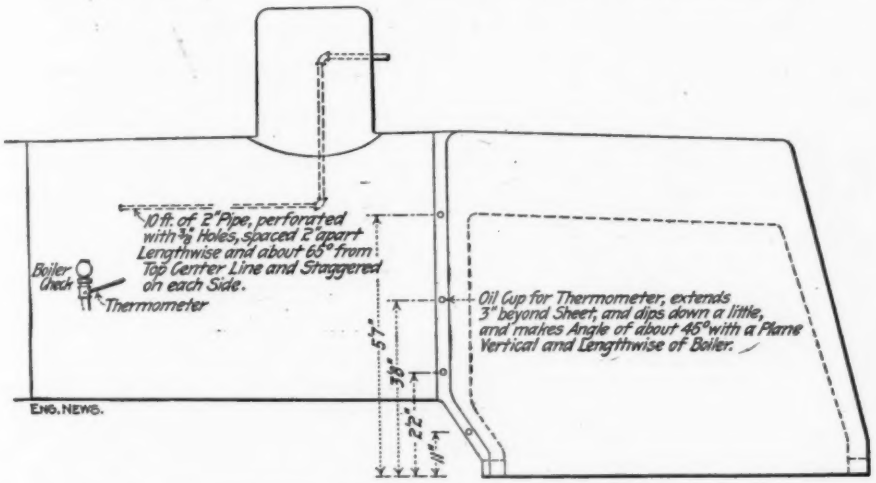

10 ft. of 2" Pipe, perforated with 3/8" Holes, spaced 2" apart Lengthwise and about 65° from Top Center Line and Staggered on each Side.
Boiler Check
Thermometer
Oil Cup for Thermometer, extends 3" beyond Sheet, and dips down a little, and makes Angle of about 45° with a Plane Vertical and Lengthwise of Boiler.
57"
38"
22"
11"
ENG. NEWS.

FIG. 5.—Temperature Tests Injected Water-location Thermometers.

injected water some tests were made with thermometers inserted into the side of the boiler as shown in Fig. 5. The apparatus consisted of a brass oil cup and extended about four inches into the water and this held an ordinary chemical thermometer and a guard made of gas pipe which protected the thermometer. The oil cup and thermometer guard are shown in Fig. 6.

It will be noted that the oil cups were inserted into the left front corner of the outside fire box sheet, one about on a level with the crown sheet, one about seven inches above the mud ring and two applied in between. They were placed just a little ahead of the back tube sheet. One thermometer was

also arranged in the delivery pipe just below the boiler check, in order to get the temperature of the water before entering the boiler.

The method of test was to get the water level at or near to the bottom of the glass, raise steam pressure to 195 pounds, as shown by the gauge on the engine, and take temperature readings. The tests were made in the round house, steam being produced by firing the engine with bituminous coal. They were intended to simulate the condition of an engine that has just arrived at a station, and whose injector is applied to pump water while the engine is standing still. Having obtained the water level and pressure as before mentioned, the injector was applied and the boiler filled to the top of the glass, temperature

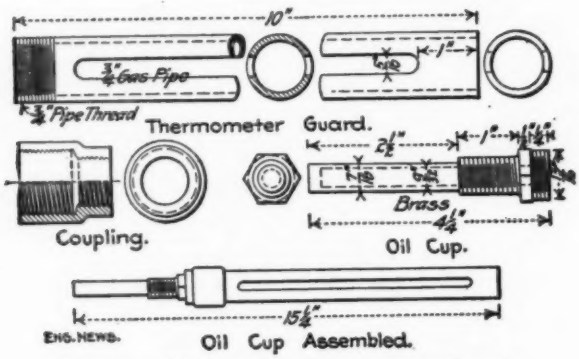


FIG. 6.—Oil Cup and Thermometer Guard.

readings being taken every minute in most of the tests. The results of the tests are shown on plotted diagrams, Figs. 7 and 8.

Test No. 1 was made by injecting the water through the left boiler check in the ordinary manner, all of the thermometers being also on the left side. It will be noted that the highest thermometer, which was on a level with the crown sheet, did not drop very much in temperature, but the lowest thermometer started to drop as soon as the injector was applied and during the filling of the boiler, dropped about 105 degrees.

Test No. 2 was made in the same way and showed about the same results.

Test No. 3 was made by delivering the water through a pipe run for convenience through the whistle hole in the dome

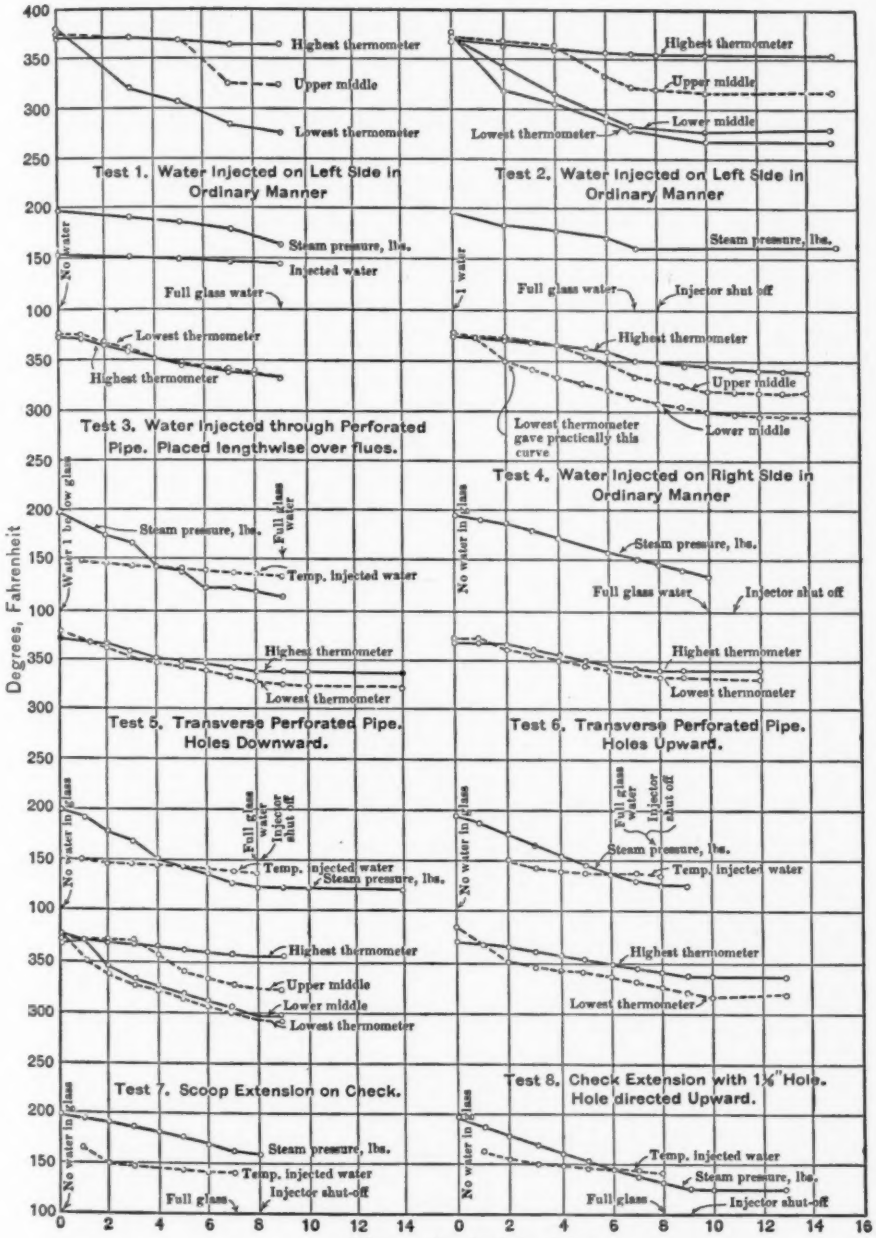


Fig. 7. Temperature Tests of Injected Water.

then down to the flues, and finally through ten feet of two inch pipe placed lengthwise over the flues. This last length of pipe was perforated with three-eighth inch holes spaced two inches apart lengthwise about 65 degrees from the top center line and staggered on each side. This pipe is also shown in Fig. 5. It will be noted in this test that where the water was delivered through the perforated pipe the highest and lowest thermometers had about the same temperature at all stages of the filling

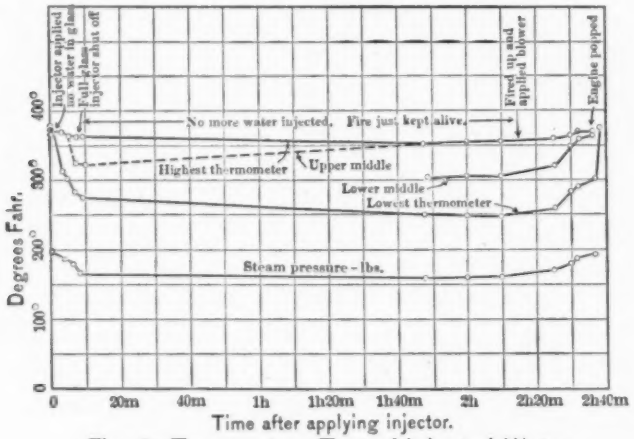


Fig. 8--Temperature Test of Injected Water.

of the boiler, showing that the injected water was well mixed with the water already in the boiler.

I may say here that before starting in on the test, in order to determine the amount of water required to fill this boiler, we ran the water through a three-inch Crown water meter and found that to fill the boiler to the bottom of the water glass took 289 cubic feet and to the top of the glass 50 feet additional, or in round figures this would be 2,400 and 415 gallons, respectively. In other words, if we have water in the boiler to the bottom of the glass and then add water to the top of the glass, we add 17 per cent. additional water.

Test No. 4 was made by delivering the water into the boiler on the right side in the ordinary manner while temperature readings were taken on the left side. It will be noted that the lowest thermometer dropped about 45 degrees below the highest

during the filling of the boiler from the bottom to the top of the glass.

In comparing tests 1 and 2 with test No. 3 there is one very interesting point, namely, much greater drop in steam pressure during test No. 3. The explanation for this is undoubtedly that in tests 1 and 2 the injected water did not get mixed very much with the upper layer of water and therefore did not condense much steam, while in test No. 3 the mixture was very thorough and a correspondingly greater amount of steam was condensed.

Test No. 5. In this test the water was delivered into the boiler through a perforated pipe placed transversely over the flues, the pipe being an extension on the boiler check. To carry out this arrangement the boiler check was raised 15 inches above its present location, so as to bring it above the level of the flues. A special brass flange was made that would fit the contour of the boiler at this point. The flange was fitted to the boiler and a bushing screwed into the flange, the pipe being previously screwed into the bushing, and lastly, the check was screwed into the bushing also. The pipe was four feet, of two-inch size, perforated with half inch holes spaced about 1¼ inches apart lengthwise about 65 degrees from the top center line, and staggered on each side. The pipe was put in so that the holes face downward. It will be noted that the mixing of the injected water with the water in the boiler was fairly satisfactory, although not quite as good as in test No. 3 where the longitudinal pipe was used. In plotting results of this test only the readings of the highest and lowest thermometers are shown. As the two middle thermometers gave readings coming in between these two, their readings were not plotted, as this would cause confusion.

Test No. 6. This test was made the same as No. 4, except that the holes faced upward instead of downward. The results show about the same as No. 5, except that the mixing was slightly better.

At this point in the course of our tests it was thought desirable, if possible, to get some arrangement or extension attached to the check that would turn the water upward and in this manner get the mixing of the injected water with the water in the boiler. For this purpose we made the following tests:—

Test No. 7. In this test we attached a sort of scoop ex-

tension to the check turned upward at the end, but open on top. A trial was made of this to see how it directed the course of the water by running hydrant water through the check with this attachment out into the open air. It was found that the water was turned upward but spread out fan-shaped. The results of this test showed that this device did not accomplish the desired mixing.

Test No. 8. It seemed now that what was necessary was to direct the water upward with more velocity and in a more solid stream, so that the delivered water would get toward the

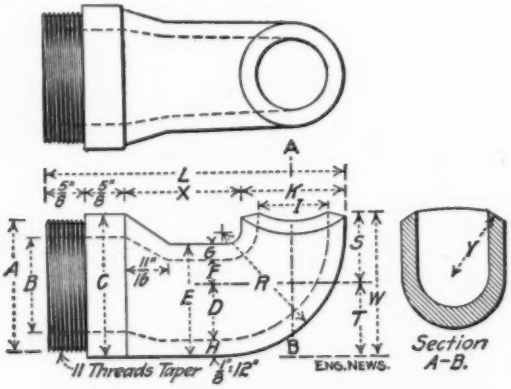


FIG. 9.—Elbow Check Extension.

top before the resistance stopped its progress and turned it downward. For this purpose we made a brass extension screwed into the check, extending almost to the flues and closed at the end, but with a $1\frac{1}{8}$ inch hole bored into it, facing upward. Tests made of this with cold water, as before mentioned, showed that the water was directed upward with some force, but the stream was not a solid one, although it was considered sufficiently satisfactory for making a test. It will be noted from the results that the mixing was fairly satisfactory, but possibly could be improved by having the water directed upward in a more solid stream.

It will be noted from the above results that when the injector is applied with ordinary boiler feeding arrangement and no steam is being drawn, the water flows toward the bottom of the boiler and cools the lower parts in some cases 100 degrees

in a very few minutes time. This of course results in putting considerable stress on the lower parts of the fire box sheets and probably aggravates the development of cracks.

After some experimenting and close watching of the flue work, the Chicago, Burlington and Quincy Railway adopted on all engines the elbow extension to the boiler check as shown in Fig. 9.

TEMPERATURE TESTS FIRING UP.

By the ordinary method of firing up a locomotive boiler where a bank of fire is made in the back part of the fire box,

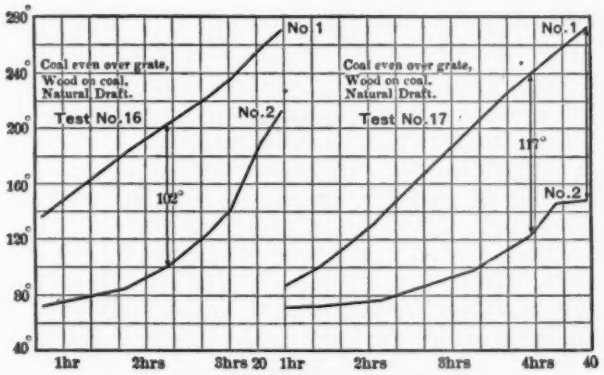


Fig. 10.--Firing up Tests.

the upper layers of water heat faster than the water at the mud ring and below the flues, with a result that differences of temperature may exist between mud ring and crown sheet of 200 degrees.

The results of some temperature tests of firing up are shown in Fig. 10, and an arrangement intended to produce circulation and get more uniform temperature in the boiler is shown in Fig. 11, a nozzle arrangement through which steam or air can be injected into the water and in this way produce a movement upward. A trial of this arrangement has shown that steam produces local elevations of temperature, and by means of air a more uniform temperature is obtained. Fig. 12 shows the position of the nozzle and of thermometers Nos. 1 and 2

in the boiler The results of tests of this nozzle are shown in Fig. 13.

Although fair results as regards uniformity of temperature can be produced by injecting some air into the boiler near the mud ring, still some inconvenience is attached to its use, and the arrangement has been used only in an experimental way. Further although the differences of temperature in the ordinary method of firing up are great, still they are comparatively not

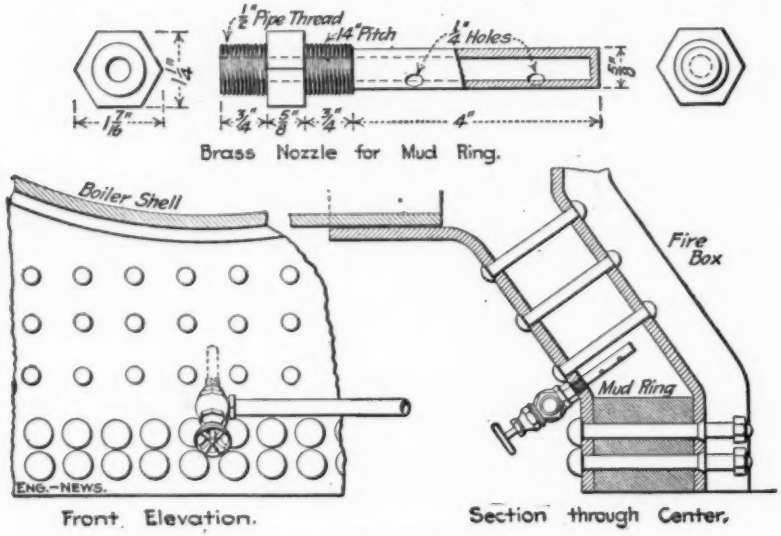


FIG. 11.—Firing up Nozzle.

frequent, and do not occur suddenly, and it seems a little doubtful whether much trouble can be attributed to the temperature differences occurring while firing up.

SPECIFICATIONS FOR FIRE BOX STEEL.

The extreme limits for tensile strength of the various American specifications require fire box steel to have 50,000 lbs. per square inch as a minimum and 65,000 lbs. as a maximum. In foreign specification, the minimum limit seems frequently to run below 50,000 lbs. per square inch. Formerly the American requirements for tensile strength were 50,000 lbs. as a minimum and 60,000 lbs. as a maximum. About fifteen years ago

these limits were raised and were made 55,000 to 65,000 lbs. respectively, based apparently on the initiative of the Pennsylvania Railroad Company. Within the last few years, however, there has been a tendency to lower the limits, and the present limits of the American Railway Master Mechanics' Association are 52,000 to 62,000 lbs. It will be seen from what has been presented above that under ordinary conditions of service, the locomotive boiler (including fire box and especially the lower parts) is frequently subjected to severe over-heating, differences of temperature and severe and sudden changes of temperature around the lower parts of the fire box and lower flues. It seems to be the result of experience that the harder grades of fire box steel do not stand these abuses satisfactorily, but seem

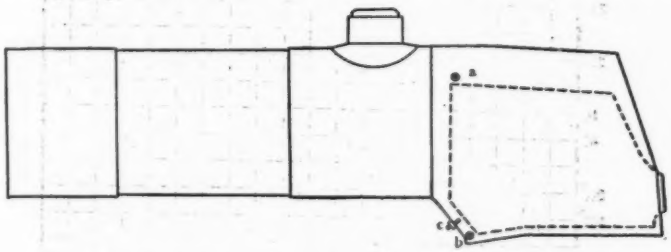


FIG. 12.—Position of Thermometers and Fire Up Nozzle.
a. Thermometer No. 1. *b*. Thermometer No. 2.
c. Fire Up Nozzle.

to develop cracks and ruptures and very soft steel under similar conditions seems to stand these abuses a longer time before failure occurs, and in fact, may become badly corrugated and distorted and still remain serviceable. It has been my experience that, as a general proposition, where fire box sheets fail from single rupture without otherwise being badly cracked or corrugated, that the carbon runs toward .25 per cent. or higher and may run as high as .35 per cent. On the other hand, the sheets which fail by corrugation and gradual cracking generally contain carbon between .12 to .25 per cent. It seems therefore that as a general proposition, the softer grades of fire box steel give better service than the harder grades, and the Chicago, Burlington and Quincy Railway Company has recently changed the requirements for fire box steel to tensile strength running

from 50,000 to 58,000 lbs. per square inch, the former limits being from 55,000 to 65,000 lbs. per square inch.

It seems clear to the author, however, that the problem of long life of fire box steel is not so much a question of quality of

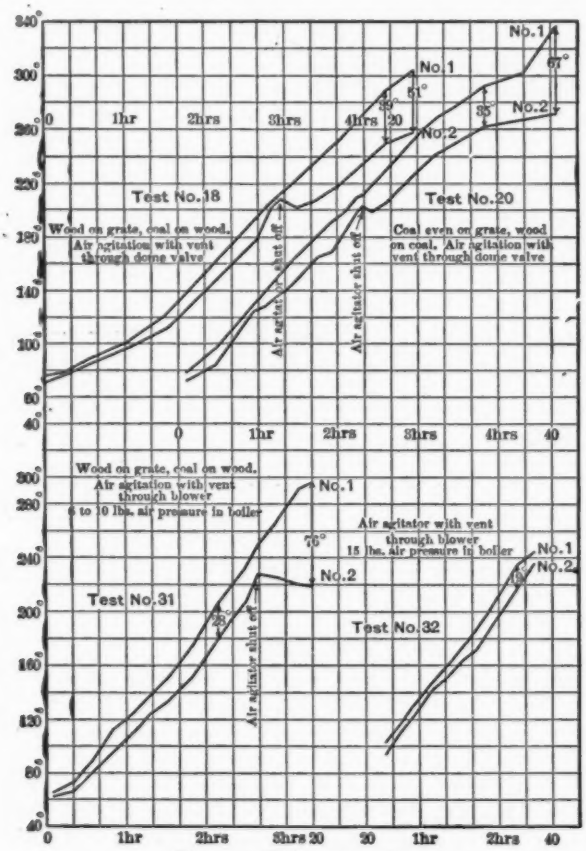


Fig. 13--Firing up Tests.

steel, but is mostly up to the railroads. By suitable treatment of the water supplies, a proper arrangement for delivering feed water into the boiler, and proper methods of caring for boilers in round house and elsewhere, long life can be expected with any grade of fire box steel and most of the complaints of poor steel are then apt to disappear.

TREATMENT OF WATER.

A matter that is very intimately tied up in the problem of the care of boilers is treatment of water. The author has studied this matter chiefly in connection with flue work, but as the good performance of flues and fire box steel go hand in hand it may be interesting to record the results of some investigations concerning the relation of flue work and hardness, particularly permanent hardness, of the water.

In order to get some comparison of the amount of flue work and boiler washing done on switch engines at the various places on the Chicago, Burlington and Quincy Railway system, I arranged to get the numbers of switch engines working at some twenty-two places during July, 1905. I then arranged to take from our records the amount of flue work and boiler washing done on these engines. This comparison is intended largely to note if possible, what relation there might be between the quality of the water supply and the flue work and boiler washing done.

I give below a summary of the figures obtained:—

Place	Number of Engines	Miles per Flue Calked	Miles per Washing	Source of water—Remarks	Hardness parts per 100,000
Chicago	36	5.8	700	Lake Michigan	13.
Aurora	7	18.9	3,338	Fox River—Softene	14.
Galesburg	10	91.2	1,112	Lake Rice—Treated with soda ash.	19.
Quincy	4	23.3	3,315	Mississippi River—Lime treatment—Jewell filter.	13.
Beardstown	3	28.2	659	Illinois River	25.
Burlington	8	62.1	2,368	Mississippi River—Softened	12.
Ottumwa	6	12.3	898	Des Moines River	25.
Grand Crossing	4	18.6	2,816	Black River, Wis.	9.
Dayton's Bluff	6	5.9	1,111	Mississippi River	10.
Savanna	2	275.0	2,291	Deep well—Softened	13.
Creston	4	76.8	1,153	Artificial lake	18.
Hannibal	5	No flues calked	1,993	Mississippi River—Settled in reservoir.	23.
N. St. Louis	9	32.5	598	Mississippi River—Lime treatment—Settled.	18.
St. Joseph	12	12.7	876	Missouri River—Settled in reservoirs.	35.
Kansas City	10	14.3	708	Missouri River	35.
Brookfield	5	4.8	460	Yellow Creek	18.
Omaha	6	43.6	762	Missouri River	43.
Lincoln	9	7.2	792	Wells—62 feet deep	24.
McCook	2	No flues calked	550	Wells at Republican River	28.
Denver	6	14.6	762	Wells	38.
Alliance	3	26.5	629	Three wells	27.
Sheridan	3	14.4	221	City water from Big Goose Creek.	26.

I have also plotted the hardness against the miles per washing and miles per flue calked as shown in Fig. 14. In look-

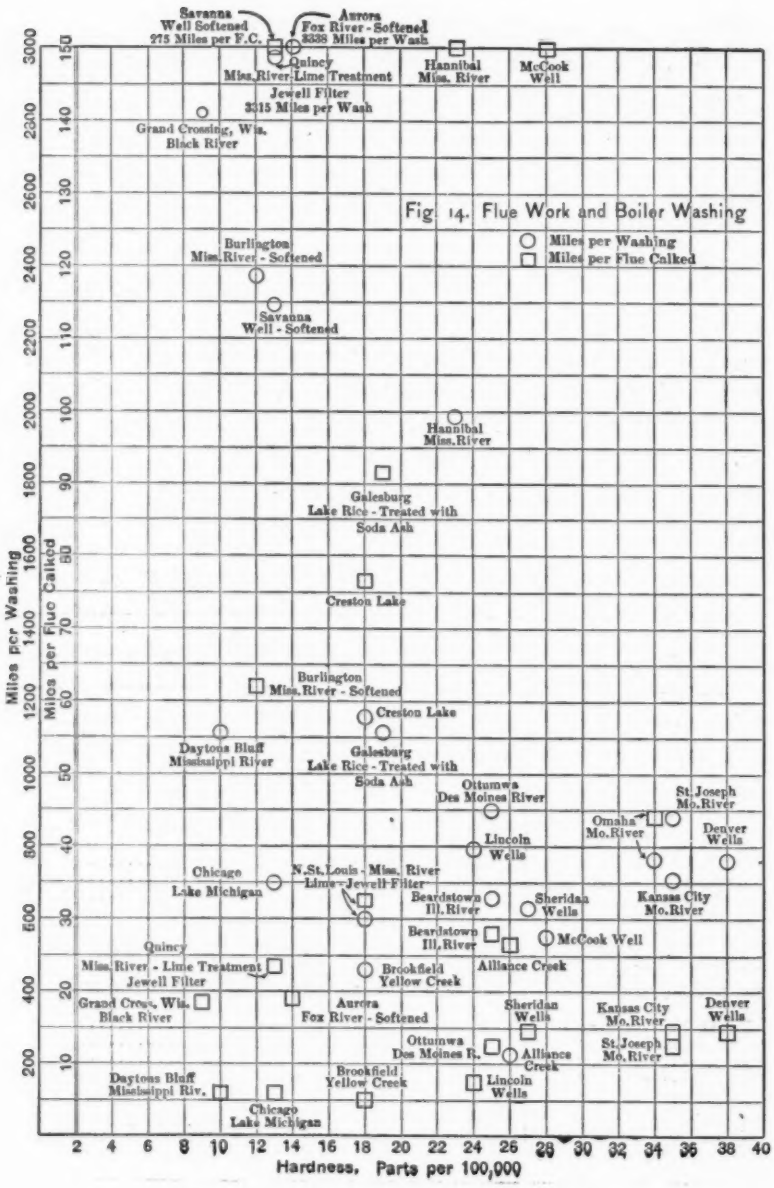


Fig. 14. Flue Work and Boiler Washing
Miles per Washing
Miles per Flue Calked
Savanna Well Softened 275 Miles per F.C.
Aurora Fox River - Softened 3338 Miles per Wash
Quincy Miss. River - Lime Treatment Jewell Filter 3315 Miles per Wash
Hannibal Miss. River
McCook Well
Grand Crossing, Wis. Black River
Burlington Miss. River - Softened
Savanna Well - Softened
Hannibal Miss. River
Galesburg Lake Rice - Treated with Soda Ash
Creston Lake
Burlington Miss. River - Softened
Creston Lake
Daytons Bluff Mississippi River
Galesburg Lake Rice - Treated with Soda Ash
Ottumwa Des Moines River
St. Joseph Mo. River
Omaha Mo. River
Denver Wells
Lincoln Wells
Chicago Lake Michigan
N. St. Louis - Miss. River Lime - Jewell Filter
Beardstown Ill. River
Sheridan Wells
Kansas City Mo. River
Beardstown Ill. River
McCook Well
Quincy Miss. River - Lime Treatment Jewell Filter
Brookfield Yellow Creek
Alliance Creek
Grand Crossing, Wis. Black River
Aurora Fox River - Softened
Sheridan Wells
Kansas City Mo. River
Denver Wells
Ottumwa Des Moines R.
Alliance Creek
St. Joseph Mo. River
Daytons Bluff Mississippi Riv.
Brookfield Yellow Creek
Lincoln Wells
Chicago Lake Michigan
Hardness, Parts per 100,000

FIG. 14.—Effect of Treatment of Water.

ing this figure over closely, in a general way it may be said that the miles per washing decrease as the hardness increases, which is a result that would be expected. There seems to be no relation, however, between the total hardness and the miles per flue calked, some of the lowest results being with the soft waters. Looking more closely into this feature, it will be noted that the cases where the miles per flue calked are large are the ones where the water has either been softened in a softening plant or has been treated with soda ash. In cases where the softening plant is used, part of the treatment consists of the use of soda ash, and thus it will be seen that in all cases where the miles per flue calked are high, the water really had sufficient soda ash put into it to combine with the permanent hardness or calcium sulphate.

McCook water, as far as I am aware, is not treated with soda ash, but this is one that naturally has no permanent hardness and at times naturally has a little alkali carbonate or soda ash. The Creston record is among the high ones, but this water generally has only a small amount of permanent hardness. Hannibal gives a very high record, although the Mississippi River water at this point has several parts of permanent hardness, and this therefore seems to be the only prominent exception to the rule which we can now formulate; namely, that the amount of flue work, as far as quality of water is concerned, is a function of the permanent hardness, and within the limits of such waters as we have to use (say 40 parts per 100,000 of total hardness) the amount of flue work seems to be independent of the total hardness. Analyses of water taken from boilers have shown that the permanent hardness keeps concentrating in the boiler up to perhaps ten or twenty or more parts per 100,000, while if there is an excess of soda ash, the water in the boiler will have very little hardness, amounting to perhaps five parts per 100,000

I think I may now express this as the general rule that where water is free from excessive mud or alkaline salts, the amount of boiler washing under present usual arrangements on the Chicago, Burlington and Quincy Railway is a function of total hardness, while the amount of flue work is a function mostly of the permanent hardness or calcium sulphate.

CONCLUSION.

In conclusion, the author suggests that long life of fire box steel is to be obtained; first by suitable treatment of feed water; generally plain soda ash treatment sufficient to destroy all sulphate of calcium will answer the purpose, but where the water is very hard softening with lime will also be desirable; second, by avoiding considerable and sudden variations of temperature due to cold feed water dropping to the bottom of the boiler when active steam production is not going on. Some feed water arrangement should be used which will not allow the water to thus segregate; third, by keeping the boiler continuously hot and avoiding wash-outs especially with cold water; a blow-off pipe on the back mud ring connected to a blow-off cock in the back corner in conjunction with a system of blowing will keep the boiler free from all accumulations if the water has been suitably treated. The blowing out is also necessary to keep the concentration of the water below the foaming point, say 200 parts per 100,000.

If the above are done probably the quality of fire box steel is of secondary importance, but the author suggests that the quality of steel called for in the specifications of the American Railway Master Mechanics' Association, tensile strength of 52,000 to 62,000 pounds will probably in general be most satisfactory.

THE EFFECT OF COMBINED STRESSES ON THE ELASTIC PROPERTIES OF IRON AND STEEL.

By E. L. Hancock.

The tests reported below were carried out as a part of the "program of work" outlined by the writer, and presented to the Society in a Preliminary Report on the Effect of Combined Stresses on the Elastic Properties of Iron and Steel (see Proceedings, Vol. V, p. 179). This report gave the results of tests on certain specimens of low carbon steel and nickel steel. The specimens were tested in tension while under different torsional stresses, i. e., in tension while under torsion to $\frac{1}{3}$, $\frac{2}{3}$, and the full elastic limit in torsion, respectively. The results showed that the torsional stresses lowered the elastic limit in tension.

The additional tests reported in this paper were made, for the most part, on steel tubing; the method of testing and general procedure being about the same as that reported for the nickel and carbon steel solid rounds. Some tests were also made on low carbon steel, solid rounds in compression while under torsion, the latter being the beginning of a series of tests in compression-torsion. Only a part of the results of these tests is included in this report. The tests were all made under the direction of the writer in the laboratory for testing materials of Purdue University. Acknowledgment is here made of the help given by Messrs. Carl Wagner, H. N. Hubbard, N. L. Arbuckle, O. L. Arbuckle, R. Elsea, W. Thornton, and J. T. Voshell, senior students in engineering, in connection with the tests.

Materials.

It is known that when a solid bar is subjected to torsion, the outer fibers are stressed to the elastic limit first, and that the stress varies linearly to zero at the center. It was evident that, in case a solid round was tested in tension while under torsion to, or beyond, its elastic limit in torsion, considerable tensional elasticity would be shown, since in such a case there would be a cer-

tain body of fibers in the interior of the piece that had not been stressed to their elastic limit. It was thought that by doing away with this interior core and using hollow tubes, the true effect

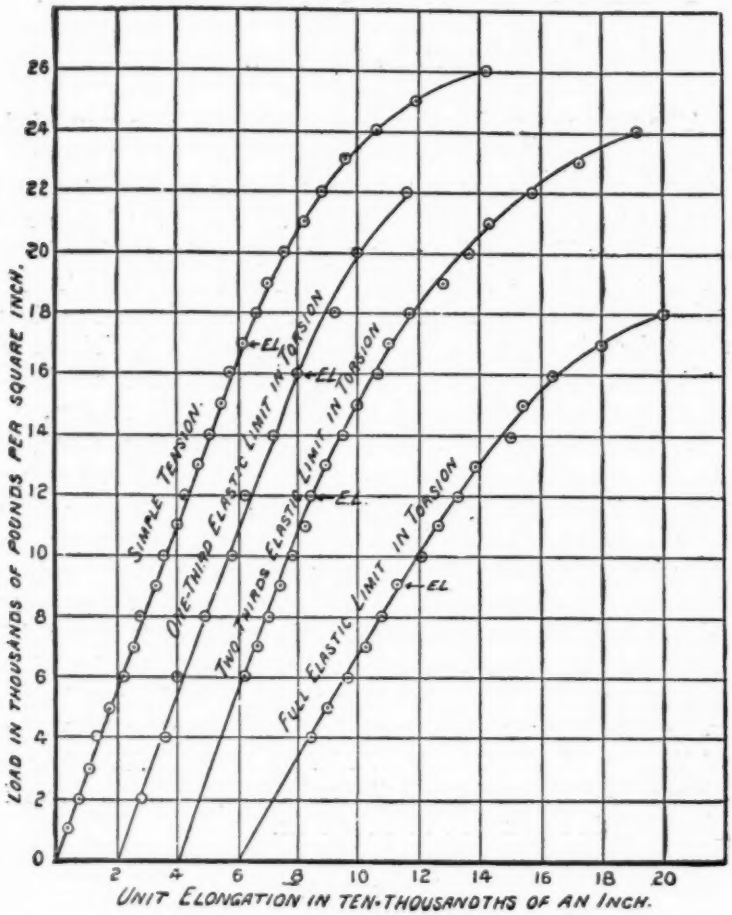


FIG. 1.—Average Curves showing the effect of combined tension and torsion on thin Steel Tubing. Average thickness .075 in.

of combined tension and torsion would be more nearly shown. It will be seen in what follows that the results of tests on thin tubing do not differ materially from those obtained from the tests of thick tubing and solid rounds, except as regards unit elon-

gation at the elastic limit (see Fig. 6). It is the opinion of the writer at this time that nothing new would be learned by using a thinner tubing than was used in these tests.

The steel tubing used in the torsion-tension tests had an outside diameter of one inch. Three different thicknesses were used as follows: 0.05 in., 0.075 in., and 0.25 in., giving an inside diameter of 0.90 in., 0.85 in., and 0.50 in., respectively. The

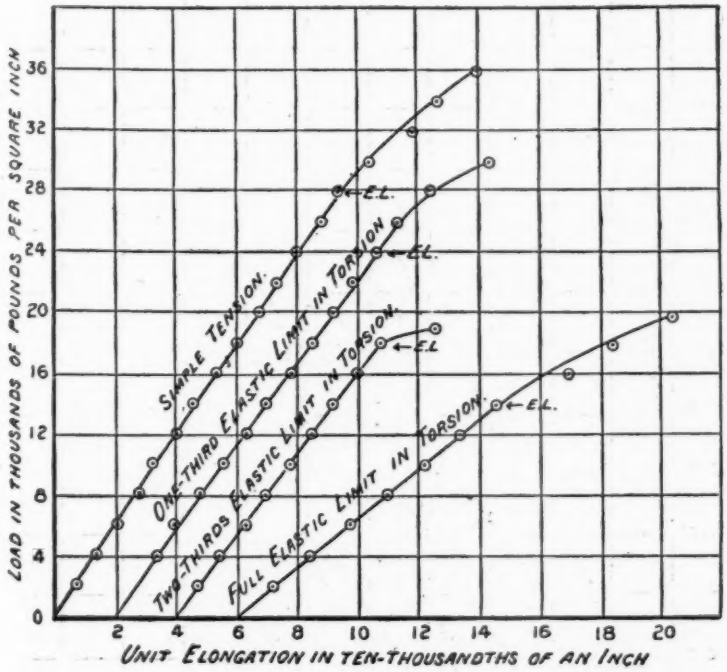


FIG. 2.—Average Curves showing the effects of combined tension and torsion on thin Steel Tubing. Average thickness 0.05 in.

tubes were thoroughly annealed before using and were, as nearly as possible, of uniform thickness. About forty torsion-tension tests were made on this material.

The material used in the torsion-compression tests was low carbon steel solid rounds. The test pieces were 8 in. long over all and turned down to $\frac{3}{4}$ in. with a gage portion turned down to $\frac{1}{2}$ in. diameter. This material was from the same shipment as the low carbon steel used in the torsion-tension tests.

METHOD OF TEST.

The apparatus used in making the tests on steel tubing was the same as that used in testing the nickel and carbon steel solid rounds (see Preliminary Report).

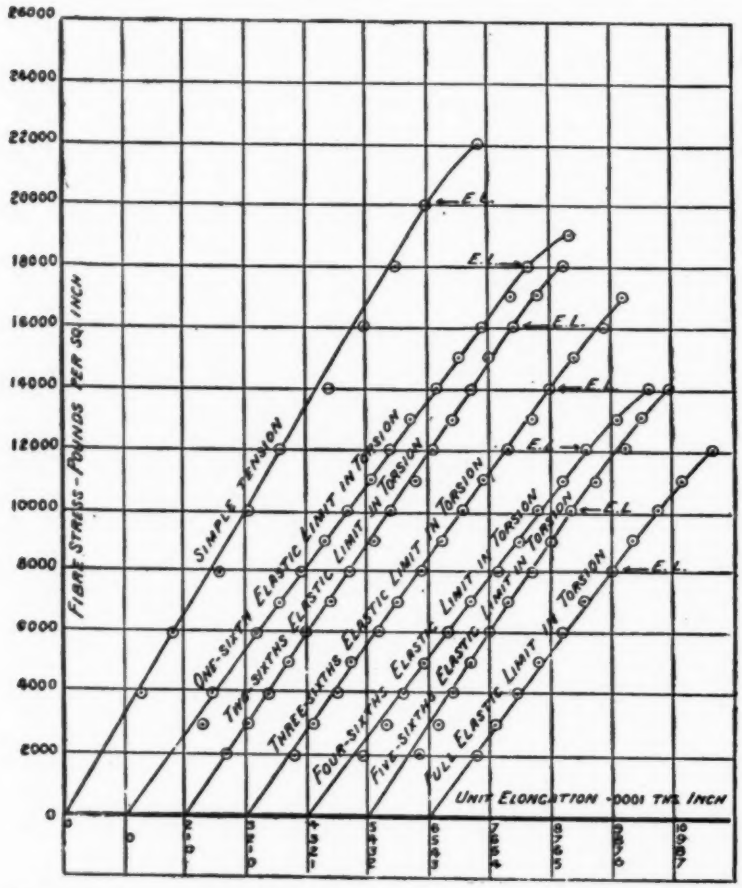

FIBRE STRESS - POUNDS PER SQ INCH
UNIT ELONGATION - 0001 THS INCH
SIMPLE TENSION
ONE-SIXTH ELASTIC LIMIT IN TORSION
TWO-SIXTHS ELASTIC LIMIT IN TORSION
THREE-SIXTHS ELASTIC LIMIT IN TORSION
FOUR-SIXTHS ELASTIC LIMIT IN TORSION
FIVE-SIXTHS ELASTIC LIMIT IN TORSION
FULL ELASTIC LIMIT IN TORSION
E.L.

FIG. 3.—Average Curves showing the effects of combined tension and torsion on Steel Tubing. Average thickness .25 in.

To make the torsion-compression tests, however, one ball-bearing head of the apparatus was placed on the platform of the machine and the other attached to the moving head. With the specimen inserted and under the desired torsional load a com-

pression test was made by lowering the moving head. The amount of compression was measured by means of an Olsen compressometer. The details of these torsion-compression tests will be given in a subsequent report.

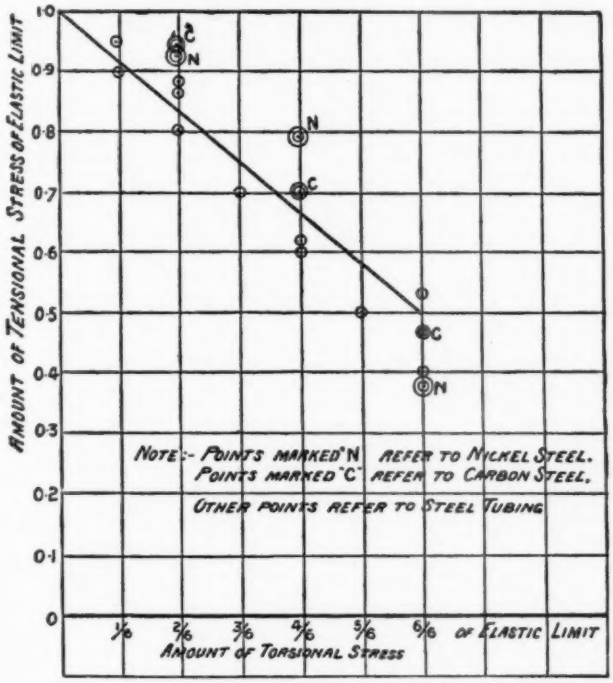


FIG. 4.—Curve showing lowering of elastic limit of Steel in tension, due to combined stresses.

RESULTS.

The lowering of the elastic limit in tension due to the presence of various torsional stresses is shown in Fig. 1 and Fig 4 and Fig. 6 (3) (for steel tubing 0.85 in. inside diameter). In this case the amount of torsional load applied was sufficient to stress the piece to $\frac{1}{3}$, $\frac{2}{3}$, and full elastic limit in torsion, respectively. Fig. 2 shows the lowering of the elastic limit in tension of steel tubing 0.90 in. inside diameter, the torsion being applied in the same way as in the case of the pieces represented in Fig. 1. Figs. 4 and 6 also show this same lowering of the elastic limit. In each

of the cases Figs. 1 and 2 the curves represent an average of two or more tests. Fig. 3 shows the effect of torsion on the elastic limit in tension of steel tubing 0.50 in. inside diameter. In this case the torsional load was applied and the piece tested in tension as indicated on the curves. Each curve represents an average of three or more tests. The lowering of the elastic limit in tension is also shown for this case by Figs. 4 and 6 (3).

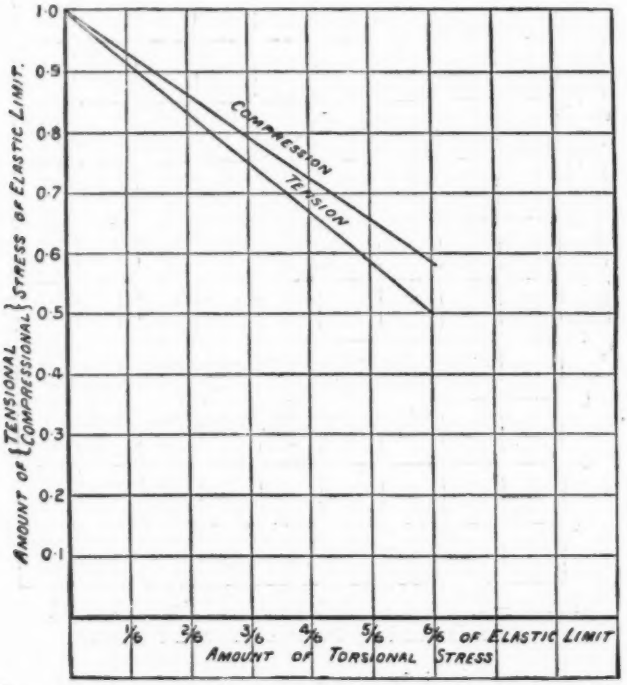


FIG. 5.—Curves showing lowering of elastic limit of Steel in tension and compression, due to combined stresses.

Fig. 6 (3) shows graphically the lowering of the elastic limit in tension for various degrees of torsion, and includes, in addition to the steel tubing, the results obtained from the nickel and carbon steel solid rounds (see Preliminary Report). The ordinates represent per cent. of lowering of the elastic limit and the abscissæ the amount of torsional stress applied. A similar statement is true for the rest of the diagrams on Fig. 6 as well as for those on Figs. 4 and 5. It is seen from this representation on Fig. 6

that the variation in the elastic limit is a linear one and might be represented by a straight line. Fig. 4 shows this straight line with the individual points represented. The equation of the line, referred to the horizontal and vertical lines as axes, might be written,

$$y = (p/2p_s)(2p_s - x)$$

where p and p_s represent unit simple tension and unit simple torsion, respectively. This same lowering of the elastic limit is shown in Tables I and II. Table I also shows the lowering of the elastic limit of low carbon steel in compression due to different torsional stresses. These latter results are shown graphically in comparison with those of the torsion-tension tests in Fig. 5. This compression line, however, only holds, so far as known, for low carbon steel.

The variation of the unit elongation at the elastic limit for different torsional stresses is shown graphically by Fig. 6 (2). It is seen that, with the exception of the cases 1 and 2 (i.e., steel tubing 0.85 in. and 0.90 in. inside diameter), the torsional stress lowers the unit elongation at the elastic limit. Fig. 6 (1) also shows the change in the modulus of elasticity in tension caused by the different torsional loads. There seems to be no regularity in this case, although in most cases the modulus of elasticity was lowered slightly by the torsional stress.

The results of the tests, as shown by the curves, might be summed up in the statement, that, *the presence of a torsional stress lowers the unit stress and unit strain at the elastic limit in tension and also lowers the modulus of elasticity, somewhat.* These same facts are also shown by Table I.

It is interesting at this time to see the results obtained by substituting the results from these tests in the various formulæ, used for determining the unit stresses for cases of combined stresses. The formulæ generally used in designing parts subjected to combined flexure and torsion, tension and torsion, and compression and torsion, are as follows:

$$q_1 = (\tfrac{1}{2})\left[p + \sqrt{p^2 + 4p_s^2}\right] \qquad (1)$$

$$q_s = (\tfrac{1}{2})\sqrt{p^2 + 4p_s^2} \qquad (2)$$

where q_1 represents the greatest unit tension on any internal plane, q_s the greatest unit shear on any internal plane, p the unit

TABLE I.

Stress Applied.	Inside Diameter in inches.	Elastic Limit in lbs. per sq. in.	Modulus of Elasticity, lbs. per sq. in.	Unit Elongation at Elastic Limit in in.
STEEL TUBING.				
Simple Tension	0.85	17,000	27,400,000	.00062
⅛ Torsion, Elastic Limit Tension	0.85	16,000	26,600,000	.00060
⅜ Torsion, Elastic Limit Tension	0.85	12,000	27,200,000	.00044
⅝ Torsion, Elastic Limit Tension	0.85	9,000	17,000,000	.00053
Simple Tension	0.90	28,000	29,700,000	.00094
⅛ Torsion, Elastic Limit Tension	0.90	24,000	27,800,000	.00086
⅜ Torsion, Elastic Limit Tension	0.90	17,000	25,000,000	.00068
⅝ Torsion, Elastic Limit Tension	0.90	14,000	16,200,000	.00086
Simple Tension	0.50	20,000	33,300,000	.00060
⅛ Torsion, Elastic Limit Tension	0.50	18,000	27,200,000	.00066
⅜ Torsion, Elastic Limit Tension	0.50	16,000	29,600,000	.00054
⅝ Torsion, Elastic Limit Tension	0.50	14,000	28,000,000	.00050
¾ Torsion, Elastic Limit Tension	0.50	12,000	26,000,000	.00046
⅞ Torsion, Elastic Limit Tension	0.50	10,000	30,300,000	.00033
⅞ Torsion, Elastic Limit Tension	0.50	8,000	26,600,000	.00030
NICKEL STEEL SOLID ROUNDS.				
Simple Tension	....	56,000	35,000 000	.0016
⅛ Torsion, Elastic Limit Tension	....	52,000	29,800,000	.00174
⅜ Torsion, Elastic Limit Tension	....	44,000	28,800,000	.00152
⅝ Torsion, Elastic Limit Tension	....	20,000	29,800,000	.00067
LOW CARBON STEEL SOLID ROUNDS.				
Simple Tension	....	34,000	30,900,000	.0011
⅛ Torsion, Elastic Limit Tension	....	32,000	30,500,000	.00105
⅜ Torsion, Elastic Limit Tension	....	24,000	25,800,000	.00093
⅝ Torsion, Elastic Limit Tension	....	16,000	25,200,000	.00063

simple tension and p_s the unit simple shear. The formulæ give the apparent maximum unit tension and shear acting on any

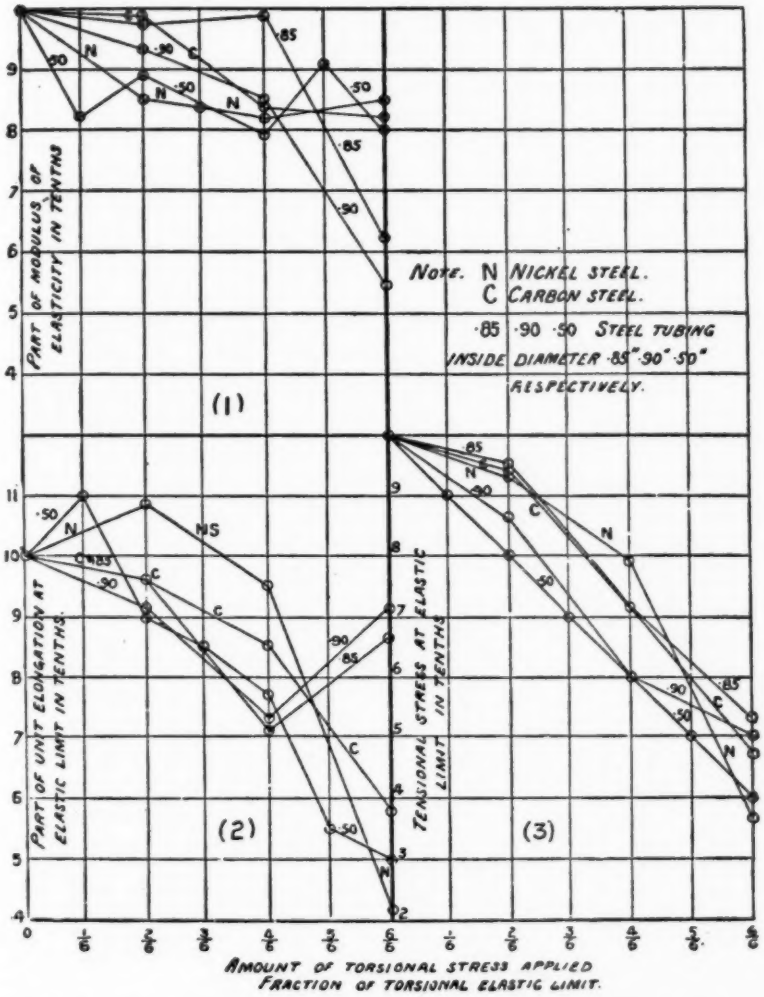

PART OF MODULUS OF ELASTICITY IN TENTHS
NOTE. N NICKEL STEEL.
C CARBON STEEL.
·85 ·90 ·50 STEEL TUBING
INSIDE DIAMETER ·85" ·90" ·50"
RESPECTIVELY.
(1)
PART OF UNIT ELONGATION AT ELASTIC LIMIT IN TENTHS.
(2)
TENSIONAL STRESS AT ELASTIC LIMIT IN TENTHS
(3)
AMOUNT OF TORSIONAL STRESS APPLIED
FRACTION OF TORSIONAL ELASTIC LIMIT.

FIG. 6.—Diagrams showing the effect of combined torsion and tension on—(1) Modulus of elasticity; (2) Unit elongation at the elastic limit; (3) Unit fiber stress at the elastic limit.

particle of the body. To obtain the true maximum unit stresses on any internal plane it is necessary to take account of the lateral

contraction as well as the elongation; i.e., it is necessary to use Poisson's ratio. Taking this ratio as $\frac{1}{4}$ (Johnson, Materials of Construction), the formulæ giving the maximum unit tension and the maximum unit shear on any internal plane are:

$$T_1 = (\tfrac{3}{8})p + (\tfrac{5}{8})\sqrt{(p^2 + 4p_s^2)} \quad (3)$$

$$T_s = (\tfrac{5}{8})\sqrt{(p^2 + 4p_s^2)} \quad (4)$$

or using Poisson's ratio as $\frac{1}{3}$ (Merriman, Mechanics of Materials, 1905) the maximum unit stresses are:

$$T_1 = (\tfrac{1}{2})p + (\tfrac{3}{4})\sqrt{p^2 + 4p_s^2} \quad (5)$$

$$T_s = (\tfrac{3}{4})\sqrt{p^2 + 4p_s^2} \quad (6)$$

Formulæ (1), (2), (3), (4), (5), and (6) have been used in constructing Table II. For this purpose p was taken as the unit stress at the elastic limit in tension, and p_s the unit torsional stress on the specimen. The unit stresses thus obtained, whether apparent or real, which are greater than the simple unit stress, are italicized. For example, low carbon steel shows a unit stress in simple tension at the elastic limit of 34,000 and a unit shear at the elastic limit in torsion of 30,000; when held in torsion at $\frac{1}{3}$ the elastic limit (corresponding to a fiber stress of 12,540) and tested in tension, the elastic limit was found to be 32,000, taking p as 32,000 and p_s as 12,540, the apparent and true stresses given in the same line have been calculated. This same procedure was followed in constructing the entire table. It is seen that the apparent maximum unit shear is generally less than the shearing strength of the material and that the true maximum unit shear is generally greater than the shearing strength of the material (here shearing strength means the elastic strength as determined from torsion tests), higher values being given for the case where Poisson's ratio was taken as $\frac{1}{3}$. In only a few cases, as that of the solid rounds and the thick tubing, did the apparent maximum tension exceed the tensile strength of the material (tensile strength meaning unit tensile stress at the elastic limit in simple tension), the number of cases where the true maximum tensile stresses, for solid rounds and thick tubes, exceed the tensile strength of the material is greater than the corresponding number for the apparent stresses.

TABLE II.

UNIT STRESSES FOR STEEL IN TENSION—TORSION.

Kind of Stress.	Apparent Stresses.		True Stresses $r = \frac{1}{4}$.		True Stresses $r = \frac{1}{8}$.		Simple Stresses.	
NICKEL STEEL SOLID ROUNDS.	q_1	q_s	T_1	T_s	T'_1	T'_s	p	p_s
Simple Tension	56000	28000	56000	35000	56000	37300	56000	.....
Simple Torsion	36000	36000	45000	45000	48000	48000	.....	36000
$\frac{1}{4}$ Torsion, Elastic Limit Tension	55400	29400	56300	36800	56000	39270	52000	13700
$\frac{1}{3}$ Torsion, Elastic Limit Tension	57700	35700	61100	44600	62200	47600	44000	28100
$\frac{1}{2}$ Torsion, Elastic Limit Tension	52500	42500	60600	53125	63300	56660	20000	41300
LOW CARBON STEEL SOLID ROUNDS.								
Simple Tension	34000	17000	34000	21250	34000	22660	34000	.....
Simple Torsion	30000	30000	37500	37500	40000	40000	.....	30000
$\frac{1}{4}$ Torsion, Elastic Limit Tension	36325	20325	37430	25430	37760	27100	32000	12540
$\frac{1}{3}$ Torsion, Elastic Limit Tension	35930	23930	38020	29020	39012	31912	24000	20710
$\frac{1}{2}$ Torsion, Elastic Limit Tension	39225	31225	45000	39000	46965	41632	16000	30170
STEEL TUBING 1 IN. OUTSIDE DIAMETER —0.075 IN. THICKNESS.								
Simple Tension	17000	8500	17000	10625	17000	11330	17000	.....
Simple Torsion	11520	11520	14400	14400	15366	15366	.....	11520
$\frac{1}{4}$ Torsion, Elastic Limit Tension	17170	9170	17460	11460	17559	12226	16000	4480
$\frac{1}{3}$ Torsion, Elastic Limit Tension	15190	9190	15987	11487	16250	12250	12000	6960
$\frac{1}{2}$ Torsion, Elastic Limit Tension	15685	11185	17355	13080	17910	14910	9000	10240
STEEL TUBING 1 IN. OUTSIDE DIAMETER —0.05 IN. THICKNESS.								
Simple Tension	28000	14000	28000	17500	28000	18670	28000	.....
Simple Torsion	16020	16020	20025	20025	21360	21360	.....	16020
$\frac{1}{4}$ Torsion, Elastic Limit Tension	25955	13955	26445	17445	26610	18610	24000	7100
$\frac{1}{3}$ Torsion, Elastic Limit Tension	22963	13963	24200	17453	24620	18620	18000	10680
$\frac{1}{2}$ Torsion, Elastic Limit Tension	22080	15080	24095	18845	24767	20100	14000	13350
STEEL TUBING 1 IN. OUTSIDE DIAMETER —0.25 IN. THICKNESS.								
Simple Tension	20000	10000	20000	12500	20000	13333	20000	.....
Simple Torsion	12000	12000	15000	15000	16000	16000	.....	12000
$\frac{1}{4}$ Torsion, Elastic Limit Tension	18222	9222	18275	11525	18295	12295	18000	2000
$\frac{1}{3}$ Torsion, Elastic Limit Tension	16947	8947	17180	11180	17360	11930	16000	4000
$\frac{1}{2}$ Torsion, Elastic Limit Tension	16220	9220	16775	11525	16967	12300	14000	6000
$\frac{1}{3}$ Torsion, Elastic Limit Tension	16000	10000	17000	12500	17333	13333	12000	8000
$\frac{1}{2}$ Torsion, Elastic Limit Tension	16183	11183	17725	13975	18243	14910	10000	10000
$\frac{1}{2}$ Torsion, Elastic Limit Tension	16650	12650	18815	15815	19537	16870	8000	12000

UNIT STRESSES FOR LOW CARBON STEEL IN COMPRESSION-TORSION.

Kind of Stress.	Apparent Stresses.		True Stresses $r = \frac{1}{4}$.		True Stresses $r = \frac{1}{8}$.		Simple Stresses.	
	q_1	q_s	T_1	T_s	T'_1	T'_s	p	p_s
Simple Compression	37000	18500	37000	23125	37000	24667	37000	.....
Simple Torsion	26000	26000	32500	32500	34667	34667	.....	26000
$\frac{1}{4}$ Torsion, Elastic Limit Compression	35535	18035	35665	22540	35712	24045	35000	4333
$\frac{1}{3}$ Torsion, Elastic Limit Compression	34200	18200	34750	22750	34934	24267	32000	8666
$\frac{1}{2}$ Torsion, Elastic Limit Compression	34330	18630	35562	24537	35970	26170	29400	13000
$\frac{1}{3}$ Torsion, Elastic Limit Compression	35315	21915	37440	27300	38160	29230	26800	17333
$\frac{1}{2}$ Torsion, Elastic Limit Compression	35613	24780	39970	30970	42040	33040	24000	21666

In the case of the thin tubing, however, it is seen that in no case did the apparent maximum unit stress or the true maximum unit stress in tension reach the elastic strength of the material, but in the case of maximum unit shear the true stresses are greater than

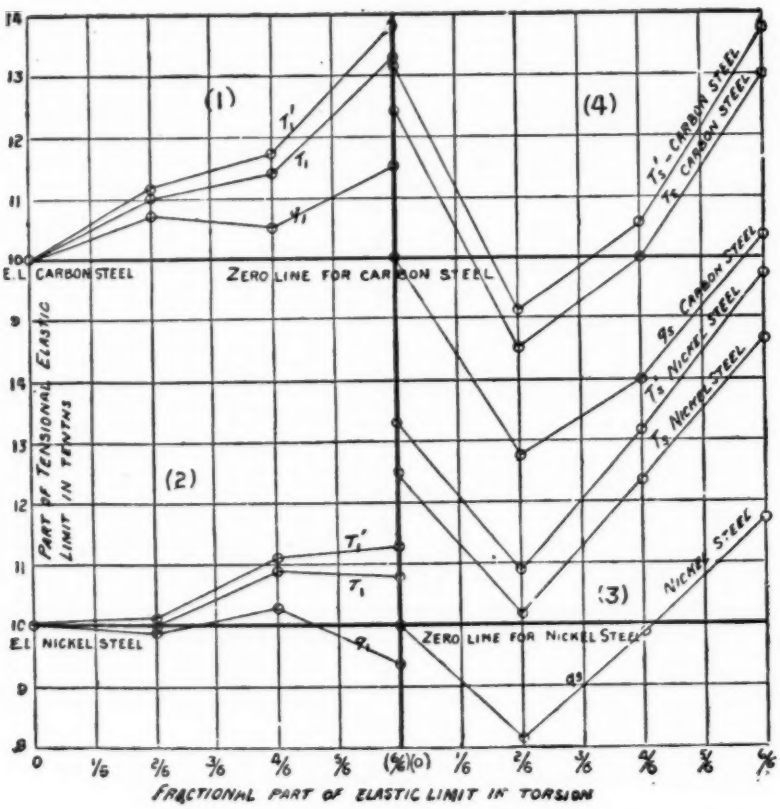


FIG. 7.—Comparison of values given by formulæ for true and apparent stresses.

the elastic strength of the material (not true for apparent maximum shear, except in one case). In general, it is seen from this table that the formulæ for true unit stresses with Poisson's ratio as $\frac{1}{3}$ give the highest values, those with Poisson's ratio as $\frac{1}{4}$, the next highest, and the formulæ for apparent stresses, the lowest.

This is shown graphically for the carbon and nickel steel solid rounds by Fig. 7.

The conclusion to be drawn from Table II is that in the design of parts subjected to combined stresses the true shearing strength should be used. Mr. J. J. Guest, whose investigation was referred to in the Preliminary Report, arrived at the same conclusion as the result of his investigations. The entire uniformity of the results as shown by the thin tubing, where the effect of the combined stresses can be more exactly determined, gives one confidence in this conclusion, in spite of the fact that the maximum tension is usually supposed to govern the design of parts subjected to combined stresses.

TESTS OF METALS IN REVERSE TORSION.

By E. L. Hancock.

It is known generally, that, in a cylindrical bar acted upon by a torsional couple, the outer fibers are subjected to the greatest stress, and the stress on the inner fibers varies as the distance from the center of the bar. If the torsional couple be sufficiently increased the outer fibers are stressed to the elastic limit of the material and any further increase causes an overstrain of these fibers, the depth of overstrain depending upon the amount that the couple has been increased beyond the elastic limit. If, now the couple be released the bar does not return to its original condition, but shows a set, and in its new condition possesses properties quite different from those possessed originally. Its strength to resist torsion is now greater in the direction of the original couple than in the opposite direction. A simple analysis shows, that *the bar is twice as strong in one direction as in the other.** This means that in its new condition the bar has two limits of elasticity, one higher than the elastic limit before overstrain and one lower. The absence of experimental data on this point led the writer to undertake a series of tests (about 150 in all) to determine the truth of the theoretical determinations as applied to iron and steel, and to determine whether or not the known phenomona shown by metals when overstrained in tension or compression, held also for torsion.

Material.—The materials tested were, low nickel steel, low carbon steel, common wrought iron and staybolt wrought iron. All specimens were about 20 in. long and tested on a gage length of 10 in. The diameters varied from 0.5 in. to 1.0 in. None of the specimens were turned down or annealed.

Method of Testing.—The tests were made in the Laboratory for Testing Materials at Purdue University, on a Riehle torsion machine of 60,000-inch pounds capacity (see Fig. 1). The sus-

*See paper by James Thompson, Cambridge and Dublin Math. Jour., Nov., 1848, and Lord Kelvin, Elasticity, Encyc. Britannica.

pended head of this machine allowed the specimen to shorten without introducing external tensile forces, and gave more accurate results than could have been obtained by using a machine where no such adaptation was possible. In order to test the materials in the reverse direction it was necessary to devise some

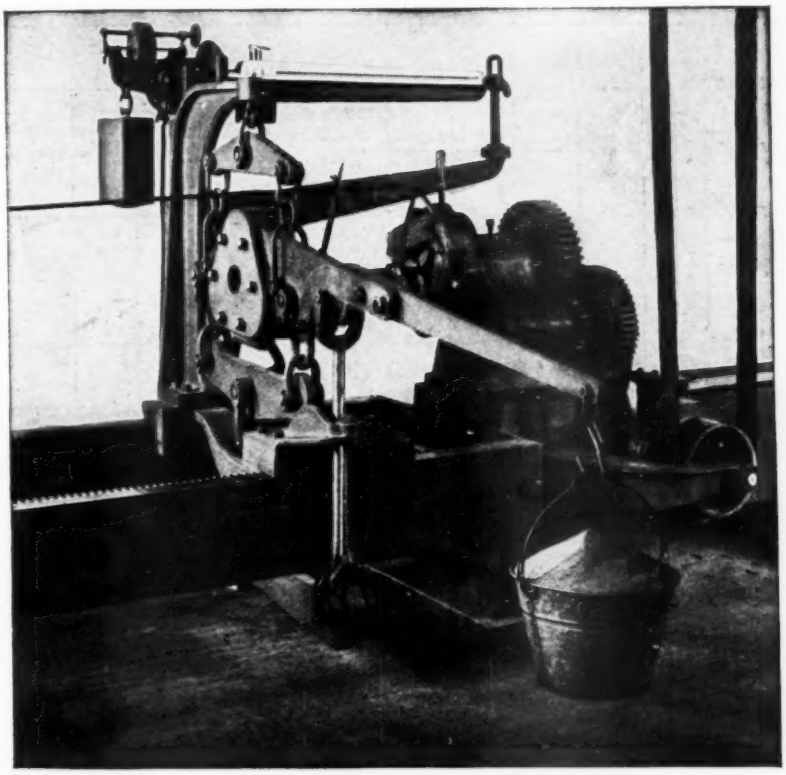


FIG. 1.

special attachment for the machine. This finally took the form of a lever attached to the suspended head, as shown. The lever carried a bucket at the free end to provide for the insertion of the weights. By reversing the jaws of the machine and also the motion it was possible to give the specimen the desired reverse twist.

After the specimen was properly inserted and the lever and bucket in place the beam of the testing machine was balanced, eliminating from consideration the weight of the parts attached. The distance from the center of the test piece to the point of attachment of the bucket being known (60 in.) made it possible to add weights to produce any desired number of inch pounds of

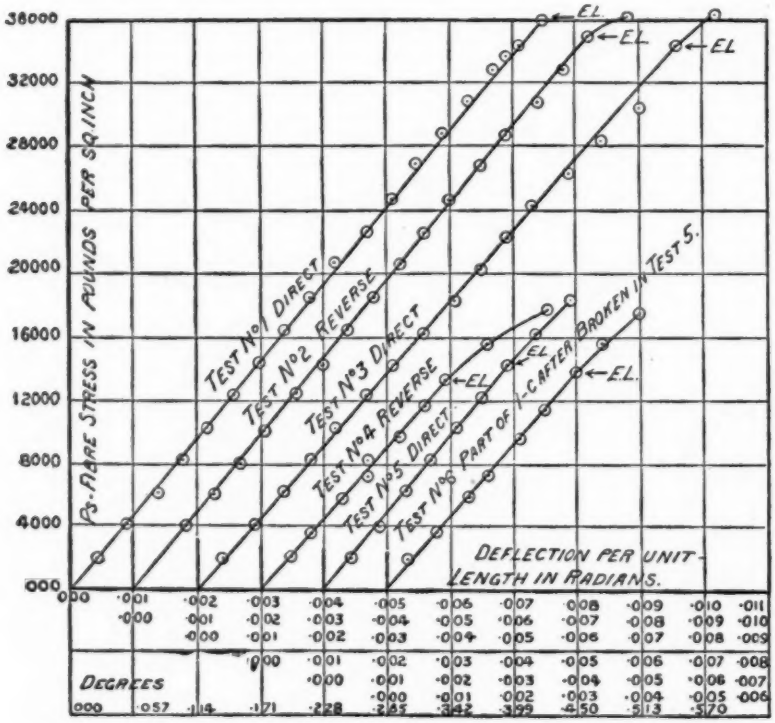


FIG. 2.—Stress-Strain Diagram. Specimen 1 C.

moment. The loads thus added caused the scale beam to rise. By running the machine in the reverse direction the load was gradually taken up by the test piece, the balancing of the scale beam indicating when all the load had been so taken up. Deformations were measured by means of an Olsen troptometer, as seen in Fig. 1, and the routine testing, in the reverse direction, consisted of adding the desired weights, running the machine backward until the specimen took up the load and then measuring

the corresponding deformation. To test the accuracy of the apparatus, a series of ordinary torsion tests were made, first with the arm attachment and then without, i. e., specimens were tested in simple torsion using the arm attachment and then others were tested in torsion in the same direction without using the arm

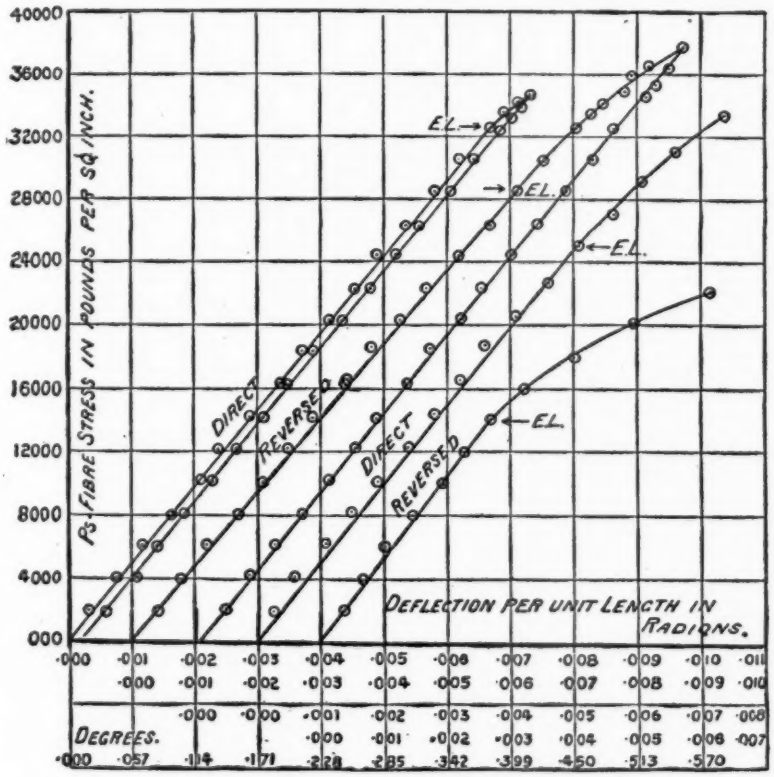


FIG. 3.—Torsion-Stress-Strain Diagram. Specimen 1 D.

attachment (in each case the specimens had not previously been tested). The results were precisely the same, showing the accuracy of the arm attachment.

Outline of Work.—As before stated the tests were made to determine the effect of overstrain, of the outer fibers in torsion, on the elastic strength of these fibers in the opposite direction, i. e., against stress of the opposite sign, or it might be stated, the

effect of overstrain in tension on the elastic properties in compression. To accomplish this the following plan of work was carried out.

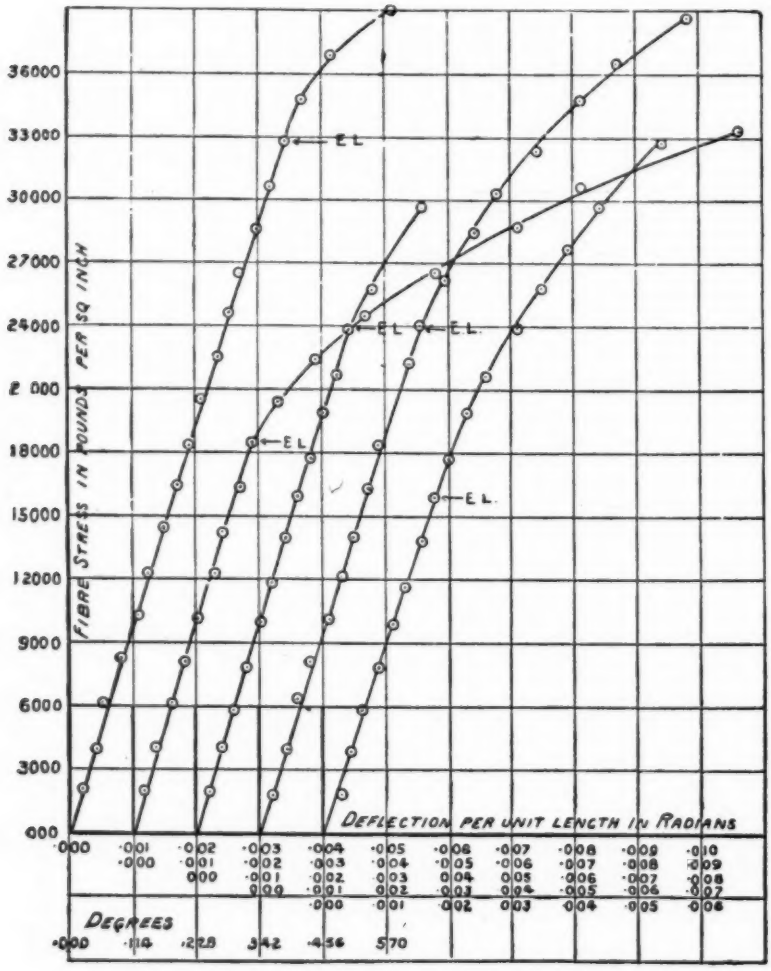


FIG. 4.—Stress-Strain Diagram. Specimen (2 C) 3.

(*a*) Bars tested in torsion to some stress below the elastic limit (proportional limit of bar) and the direction of torsion reversed immediately.

(*b*) Bars tested in torsion to the elastic limit and the direction of torsion reversed, (1) immediately, (2) after certain time.

(*c*) Bars tested in torsion to the yield point (of the bar) and then the direction of torsion reversed, (1) immediately, (2) after a certain time.

The elastic limit, as used in this paper, is the proportional limit of the bar, and the yield point, the yield point of the bar. This latter for torsion is not so definitely marked as in the case

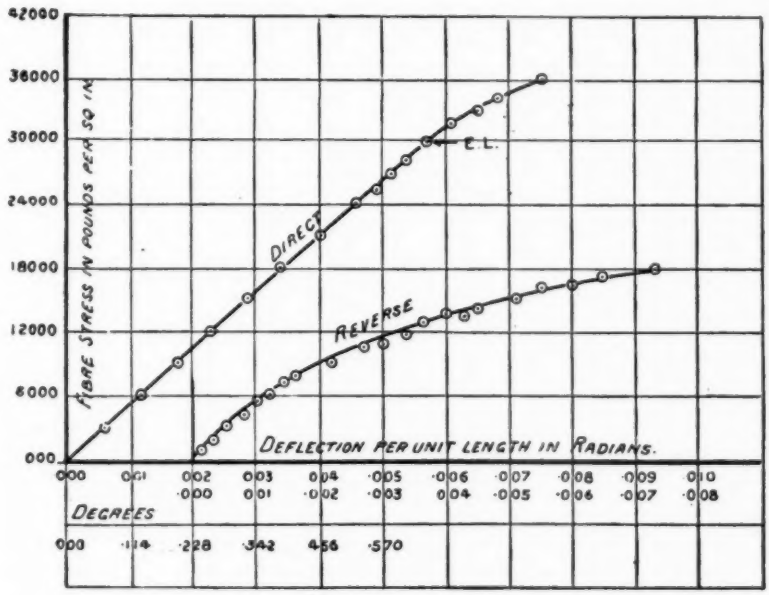


FIG. 5.—Average Curves for Nickel-Steel. Specimens A, B, C. Reversed immediately.

of tension or compression, and might, more properly, be called a *yield region*, it is to be looked for, in ductile materials, a little beyond the elastic limit where very great deformations take place for small increase of torque. The bars were considered overstrained when stress ceased to be proportional to strain.

Results.—The results of the tests outlined are shown by the following plates and tables:

Fig. 2 shows the results of tests made on nickel steel specimen (1–C).

Test No. 1—To elastic limit.

Test No. 2—Reversed after 24 hours to a point a little beyond the elastic limit.

Test No. 3—Direct to yield point (not shown on curve) after 151 days.

Test No. 4—Reversed to yield point after 6 days (yield point not shown on curve).

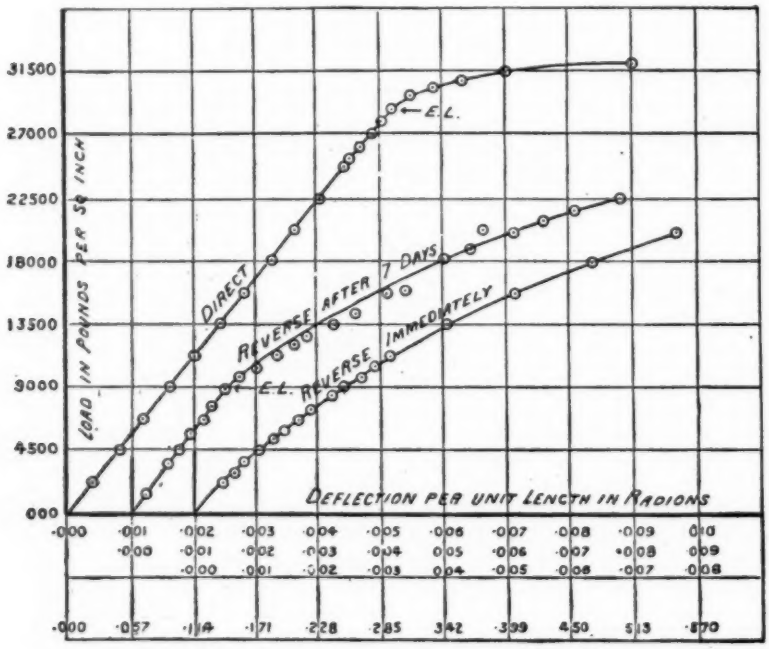


FIG. 6.—Average Curves in torsion for Mild Carbon-Steel.

Test No. 5—Direct test to rupture after 6 days.

Test No. 6—Portion of No. 5 to rupture—reverse—after 2 days.

(*Note.*—Curves are drawn only a little beyond the elastic limit in most cases.)

Fig. 3 shows the results of tests made on a nickel steel specimen (1-D). (The curves as numbered run from left to right.)

Test No. 1—Direct to elastic limit (see curve shown).

Test No. 2—Load of No. 1 held for 15 hrs. then taken off and reversed a little beyond the elastic limit.

Test No. 3—Direct to yield point after 158 days.

Test No. 4—Reversed to yield point after 5 days.

(*Note.*—Yield point in 3 and 4 not shown.)

Fig. 4 shows the results of tests of a nickel steel specimen (2–C) (3). (The curves as numbered run from left to right.)

Test No. 1—Direct to yield point.

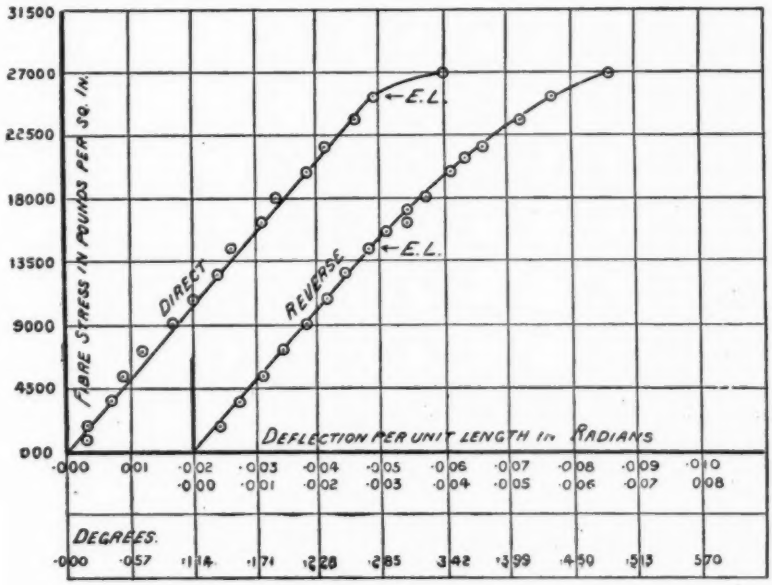


FIG. 7.—Torsion tests: Mild Carbon-Steel. Strained to elastic limit and reversed immediately.

Test No. 2—Reversed to yield point after 30 days.

Test No. 3—Direct to yield point after 151 days.

Test No. 4—Reversed to yield point after 113 days.

Test No. 5—Direct to yield point after 4 days.

(*Note.*—No attempt has been made to show the yield point in Fig. 4.)

Figs. 5, 6, 7, 8, and 9 are self-explanatory.

Results of series (*a*) where the torsion was not carried to the elastic limit in the first test, show that this test had no appreciable

effect upon the elastic properties of the material in the opposite direction. But when the stress in the first test (direct test) is carried to, or beyond, the elastic limit the elastic properties are

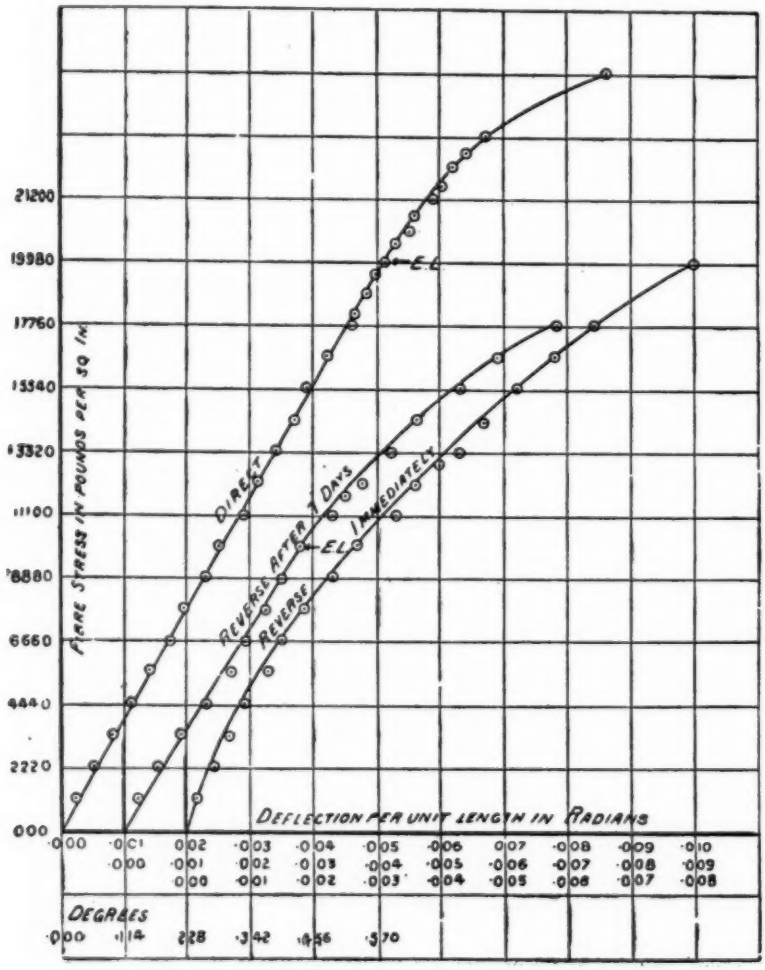


FIG. 8.—Torsion Test of Common Wrought Iron.

changed. From Fig. 2 it is seen that the elastic limit in the second test was changed very little by the first test to the elastic limit, but the elastic limit in the fourth test, due to the overstrain

in the third, is much lower (about one-third as much) even after a rest of 6 days. The fifth test gave a higher elastic limit than the fourth, due probably to the fact that the stress was in the same direction as the original. All curves are nearly parallel showing that there was little, if any, change in the modulus of elasticity. Fig. 3 shows that the first stress to the elastic limit had little, if any, effect upon the elastic limit in the reverse direction. A slight overstrain is here indicated by the set curve (fourth curve from left to right). The overstrain in this test, even after a rest of 158 days, caused a considerable lowering of the elastic limit. The overstrain in the third test reduced the elastic limit in the fourth test almost one-half. In this case the stress was reversed after five days.

When the piece was stressed to the yield point, as shown in Fig. 4, the elastic limit in the reverse direction is less than one-half of what it was at first, even after a rest of 30 days. Overstrained in this direction and allowed to rest 151 days the specimen shows an elastic limit somewhat higher than in the second test. The third overstrain with a period of rest of 113 days shows the elastic limit raised to about what it was in the third test. The fourth overstrain in the reverse direction after 4 days shows a lowering of about one-third in the elastic limit. The behavior of several pieces of nickel steel is shown by the following table.

Specimen.	Stressed to	Reversed after days to	Direct after days to	Reversed after days to	Direct after days to	Reversed after days to
1—D	e. l.	hld. 15 hr.	158 y. p.	5 y. p.	.....	.....
1	e. l.	7 e. l.	173 y. p.	.....	.....	.....
1—C	e. l.	1 e. l.	151 y. p.	6 y. p.	6 rup.	2 rup.
1—E	¾ e. l.	69, ¾ e. l.	113 y. p.	113 y. p.	4 y. p.	.....
1—B	e. l.	0 e. l.	164 y. p.	6 rup.	.....	.....
2—C	y. p.	30 y. p.	151 y. p.	113 y. p.	4 y. p.	71
Stress in pounds per sq. inch at the elastic limit for above cases.						
1—D	32,600	30,500	25,000	14,000	.....	.....
1	30,500	14,400	31,200	.....	.....	.....
1—C	36,000	35,100	34,400	13,200	14,000	13,600
1—E	Not reached.		31,800	18,800	14,000	.....
1—B	32,500	26,500	30,400	14,000	.....	.....
2—C	33,000	18,450	24,000	24,000	15,900	25,350
Average..	32,900	.....	.....	.....	.....	.....

(*Note.*—The abbreviations, e. l., y. p. and r. refer to the elastic limit, yield point and rupture respectively.)

The effect on the elastic limit of immediately reversing the stress after overstrain to the yield point is shown for certain pieces of nickel steel in Fig. 5. The overstrain destroyed the elasticity of these pieces. Low carbon steel stressed to the yield point and reversed after seven days shows an elastic limit of less than one-third the original; when reversed immediately no elasticity is

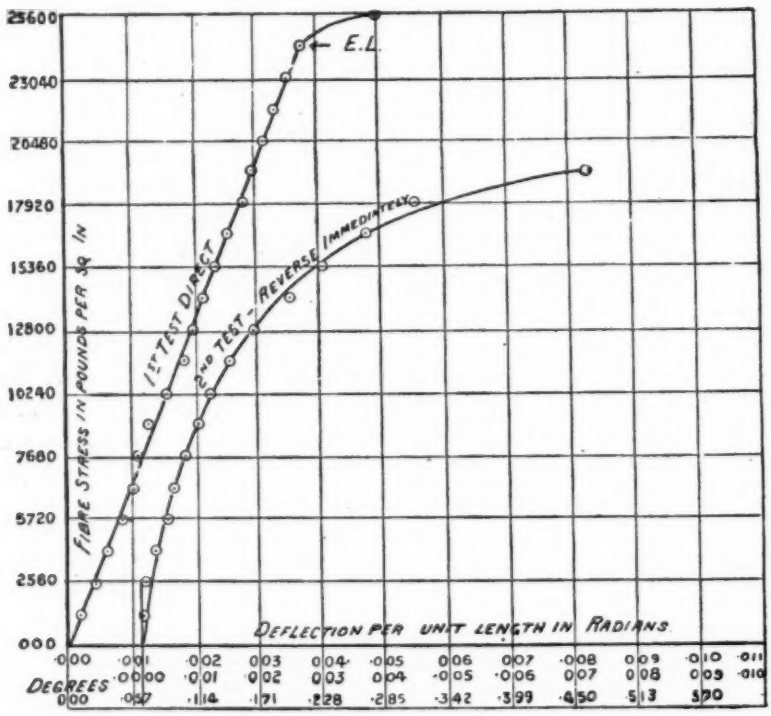


FIG. 9.—Stress-Strain Diagram: Wrought Iron in torsion. Specimens K. (Stay-bolt iron.)

exhibited (see Fig. 6). When the original stress is carried to, or a little beyond, the elastic limit, the specimens show some elasticity when reversed immediately (see Fig. 7). Wrought iron stressed to the yield point and reversed exhibits the same properties as steel (see Figs. 8 and 9).

Conclusions.—The curves show that when wrought iron or mild steel is stressed in torsion below its elastic limit (proportional

limit), its elastic properties in the opposite direction are not impaired. If the original stress be below the yield point but above the elastic limit, the elastic limit in the reverse direction is lowered but does not disappear even when the stress is reversed immediately. If the original stress be above the yield point the elasticity in the reverse direction is destroyed but reappears, gradually, after some rest. The modulus of elasticity is unchanged when the stress in the first test is below the yield point. It is not constant, for reverse tests, when the original stress is carried beyond the yield point, but comes back to its normal value after a period of rest.

The results obtained in these tests are in accord with those already worked out for tension and compression, and, indeed the present case of torsion may be considered as a unique way of changing from compression to tension or from tension to compression, as is easily seen by considering the particles of the cylindrical test piece on the 45-degree helix.

A COMPLETE MAGNETIC TESTING EQUIPMENT.

By J. Walter Esterline.

In General.—A large number of different kinds of magnetic testing instruments have been devised. Often, however, either the results obtained are only relatively accurate, or the skill, time and labor required to obtain accurate data are prohibitive.

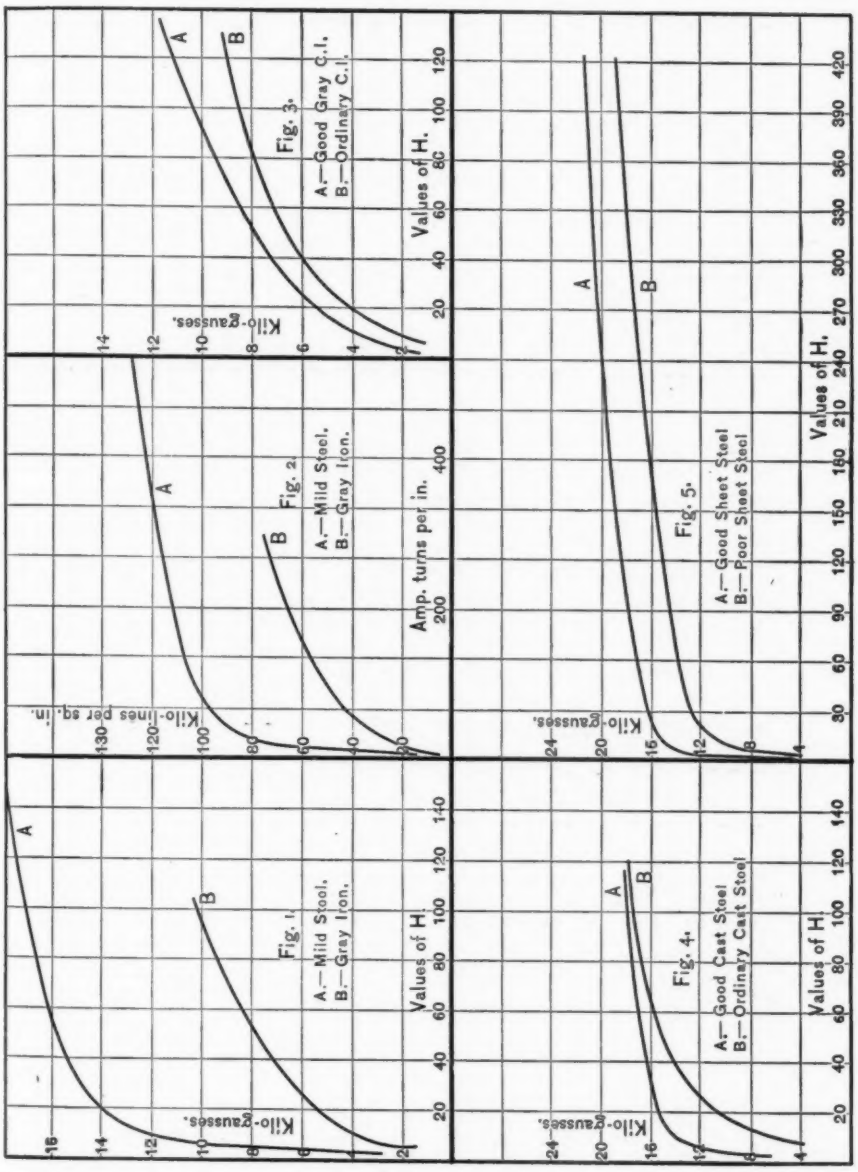
There are two magnetic properties of iron and steel which it is important to obtain, the permeability and the iron loss or core loss, as it is often called. In steel for permanent magnets, neither of these are so important as the retentivity and the coercivity or coercive force.

Permeability.—With the exception of the magnets used in most electrical instruments, practically all the magnetic material used in the construction of generators, motors, transformers and other electrical apparatus is low carbon steel or iron. The magnetism is not permanently retained by the metal, but is produced by the passage of an electric current through turns of insulated wire encircling the iron which is to be magnetized. The magnetizing force of a coil of wire is proportional to the product of the number of turns of wire and the current flowing through these turns. The ratio of the magnetic density produced in the iron, to the magnetizing force producing it, is the "permeability." Iron of high permeability is desirable, since as the permeability is higher, the magnetizing force required to produce a magnetic field of given strength is less.

Permeability Curves.—The magnetizing force may be expressed as the product of turns of wire per inch of length of the magnetic circuit, times the current flowing, i. e. ampere turns per inch, or in C. G. S. units, the Gilbert, which is equal to .796 ampere turns per centimeter of length, or 2.02 ampere turns per inch of length.

The magnetic density may be expressed in lines per square inch or in lines per square centimeter. The conventional expressions for the C. G. S. units are

	Unit.	Convention.
Intensity	Gauss	B
Magneto-motive force	Gilbert	H
Permeability	.....	$\mu = \frac{B}{H}$


Kilo-gausses.
Values of H.
A.—Mild Steel.
B.—Gray Iron.
Fig. 1.
Kilo-lines per sq. in.
Amp. turns per in.
Fig. 2.
A.—Good Gray C.I.
B.—Ordinary C.I.
Fig. 3.
A.—Good Cast Steel
B.—Ordinary Cast Steel
Fig. 4.
A.—Good Sheet Steel
B.—Poor Sheet Steel
Fig. 5.

A curve showing the relation between the corresponding values of B and H is called a B and H curve. Such curves are often incorrectly styled permeability curves.

In Fig. 1 are given the B and H curves of samples of mild steel and gray cast iron. Fig. 2 shows the curves for the same bars of iron, except that the units employed are ampere turns per inch and magnetic lines or maxwells per square inch.

It is not the purpose of this paper to discuss those compositions and treatments which affect the magnetic permeability of the different forms of iron and steel; suffice it to say that there are many things which do alter the magnetic quality, that the products of different mills and foundries vary considerably, and that the output of any foundry or rolling mill is quite likely to show considerable variation, unless close attention is given to the composition and treatment of the iron.

There are two qualities which electrical iron should possess, in so far as the permeability is concerned. The permeability should be high and the quality of the iron should be uniform.

High permeability enables the manufacturer of electrical machinery to either reduce the weight of iron and copper in a machine or gain increased efficiency, or both.

Uniform quality makes it possible to closely pre-determine the design of an electrical machine; makes possible the use of standard dimensions and windings, and reduces the necessity for the cut and try process of construction.

That the quality of the iron and steel produced in this country does vary considerably, is evidenced by reference to Figs. 3, 4, 5.

These curves are from tests of samples of iron and steel in use by different manufacturers of electrical machinery in this country. In Fig. 3 are B and H curves of cast iron from several different companies. Fig. 4 gives curves of cast steel and in Fig. 5 are similar curves of sheet steel.

METHODS OF OBTAINING B AND H CURVES.

As has already been stated there are a number of methods of testing iron for permeability. Some methods are very inaccurate; some give high relative accuracy but are not absolutely accurate; that is, a number of tests on the same sample will give

practically the same result every time, although all may be far from the correct result. Unfortunately some of the best methods require experienced, skilled operators; other good methods require a specimen which is difficult and expensive to prepare; still others require apparatus which is delicate, likely to get out of order, or to be influenced by external conditions, such as vibration,

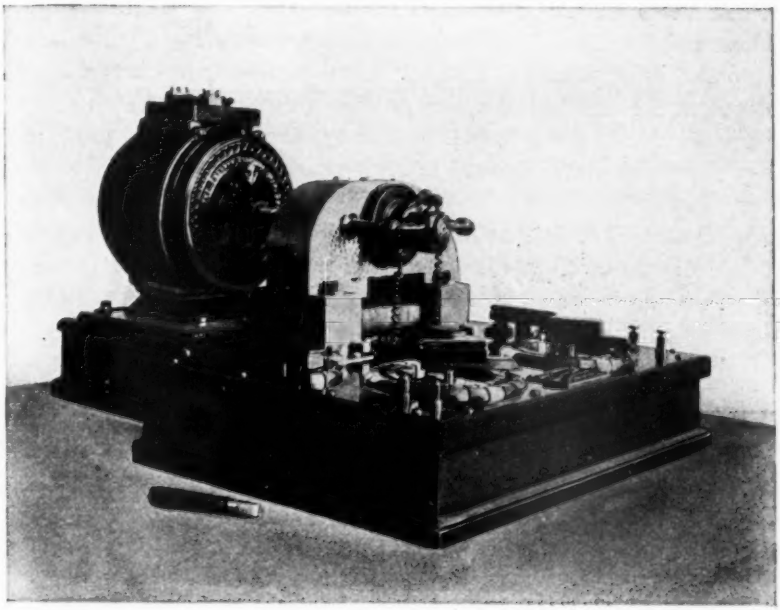


FIG. 6.

the presence of large masses of metal, magnetic fields and electric currents.

During the past ten years, the author has given considerable time to the development of a commercial form of permeameter, which would, if possible, be free from at least some of the difficulties and objections just cited. The apparatus shown in Fig. 6 consists essentially of a constant speed generator of special design, the sample to be tested forming the field magnet of the machine.

The generator is mounted on a hard rubber base, 14 in. by 18 in., which covers a sub-base containing the controlling coils, compensating resistances and shunts.

The tests bars used are straight round rods when made of solid metal. These are usually about $\frac{1}{2}$ in. in diameter and 9 in. long. When sheet samples are tested, strips $\frac{3}{8}$ in. wide, $9\frac{3}{4}$ in. long, enough to stack about $\frac{1}{2}$ in. high are used. These are either sheared from the sheet, or blanked out by means of a punch and die.

When a round bar is to be tested it is passed through the round holes in the lower part of the poles and then clamped. These holes are ground accurately to size and polished smooth, so as to obtain as perfect a joint as possible. Sheet steel samples are placed in the square holes and pressed firmly against the metal at the inner side of the square hole by means of clamping screws.

The pole pieces are made of the best grade of soft Swedish iron, forged in a single piece. The cross section is made very large throughout, so that the magnetic resistance or reluctance of this part of the circuit will be very low.

The relative areas of the bar, and other parts of the circuit are shown by the following table:

TABLE I.

Portion of Circuit.	Area compared with that of Test Bar.	Density when Density in the Bar is 16,000 Gausses.
Clamping contact at end of bar $\frac{1}{2}$ diam. ..	16 times area of bar ..	1,000
Pole pieces above clamps	24 times area of bar ..	660
Air gap at armature....	24 times area of bar ..	660
Armature core	44 times area of bar ..	360

The path of the magnetic lines is through the test bar from end to end, thence through one pole piece, through the armature core and the other pole piece to the opposite end of the test bar. From the above table it will be seen that the reluctance of the circuit other than the bar itself is very low; it is not, however, considered negligible.

The magnetizing coil consists of a definite number of turns of insulated wire, and extends the full free length of the bar between the poles. The machine can be constructed and calibrated so as to read in either set of units. When made to read in gilberts and gausses, the free length of the bar is made to be

12.566 or 4π centimeters. A constant current value of 1 ampere in the coil is used, so that H, the magnetizing force, is

$$H = \frac{4\pi N I}{10 L}$$

where N is the number of turns,
I is the current,
L is the free length of the bar in cms.

whence

$$H = \frac{4\pi \times N \times I}{10 \times 4\pi} = \frac{1}{10} N.$$

The magnetizing coil is tapped at intervals, the taps connected to the contact points of the right hand dial switch. By turning this switch, the number of active turns can be varied stepwise, and the value of H accordingly. Between the second row of contacts on the right hand dial switch are connected resistances equal to that of the portion of the coil between the corresponding contacts in the outside row, so that when turns are cut in, a corresponding resistance is cut out, keeping the resistance of the circuit constant.

Between the contacts of the left hand dial are connected coils which compensate for the small reluctance of the air gap and circuit other than the bar, while the centermost contacts of the right hand dial automatically compensate for the feeble field of flux produced by the coil, but which does not pass through the bar.

When the machine is to read in ampere turns per inch, the free length of the bar is 5 in., and the current used 1 ampere, so that

$$\text{Ampere turns per inch} = \frac{N \times I}{5} = \frac{1}{5} N.$$

The armature is specially constructed so as to give an air gap and core reluctance which is low, and yet develop sufficient voltage.

The shaft is made of tool steel, accurately ground to size; the bearings are phosphor bronze, self-oiling and aligning, with provision for adjustment after wear. The armature is driven by a constant speed motor, either alternating or direct current.

Since the speed and number of conductors on the armature are constant, the voltage developed by the armature is directly proportional to the flux set up in the test bar. The densities are

therefore read directly on the scale of a specially calibrated voltmeter, and the magnetizing force, H, or the ampere turns, as the case may be, are always indicated directly by the position of the right hand dial switch.

The reversing switch at the right hand side, changes the direction of the current in the magnetizing coils, while the left hand switch changes the direction of the voltage impressed on the voltmeter.

By means of a shunt, placed in the base of the instrument, the voltmeter can also be used to indicate the current in the magnetizing coils, by moving the small switch located between the dials.

Since the values of B and H are both read directly, no calculations are necessary, and it is possible to obtain the data for the B and H curve of sample in about two minutes.

Further, without any changes whatever, a complete hysteresis curve may be obtained with equal rapidity. The apparatus is also especially well adapted to testing steel intended for use in permanent magnets. The maximum magnetizing force can be applied at once, and the resulting density read. The turns are then reduced to zero at one step, and the residual magnetism noted. Now reversing the current while the active turns are zero, and then gradually increasing the turns until the density is zero, at which point the dial switch indicates the coercive force, or the strength with which the permanent magnetism is retained.

The author has found, by trial, that inexperienced operators having no knowledge of electricity and magnetism can obtain accurate results with the apparatus, after a little practice at reading the voltmeter scale.

The cost of preparing a sample of solid metal varies from 45 to 90 cents depending upon the labor and facilities at hand. The bars may be turned in a lathe and filed to a finish, or, what is better, turned nearly to size and finished in a small grinding machine.

The cost of preparing a sheet steel sample varies from 5 to 10 cents, depending upon the facilities.

CORE LOSSES.—The loss of power which takes place when iron is alternately magnetized and demagnetized is two-fold; hysteresis loss and eddy current loss. Both are the expenditure of energy, which appears in the form of heat. Iron may be magne-

tized and demagnetized in two ways. By moving it in the magnetic fields produced by magnetized poles which are alternately positive and negative, as in a motor or generator, or by magnetizing it directly by means of a coil of wire in which an alternating current is flowing. The transformer is an example of the second case.

HYSTERESIS.—The generally accepted theory of magnetism is that it constitutes a certain molecular state of the metal, i.e. when a bar of iron is magnetized, its molecules are arranged in a certain position with respect to each other. If the direction of the magnetic lines be changed, the position of the molecules of iron is also changed. If this be true, then when the direction of the magnetic lines is constantly and rapidly changing, as is the case in the core of an armature or transformer, the molecules of the iron are in rapid motion.

It takes energy to keep the molecules of iron moving in order to overcome the molecular friction and this energy loss is known as "hysteresis".

The harder and more dense the iron the greater is the molecular friction and the higher the hysteretic loss, so that the loss depends to a great degree upon the physical state of the metal.

As the magnetic density is increased, the greater is the relative motion of the molecules or the number of the molecules affected, so that the hysteresis loss increases as the maximum magnetic density is increased.

Obviously, also, the loss will increase as the rate at which the molecules are moved is increased, so that the hysteresis loss is practically proportional to the frequency of magnetization.

EDDY CURRENTS.—It is well known that when an electric conductor is in a magnetic field, a current is induced in the conductor whenever there is a movement of the conductor relative to the magnetic field, and vice versa.

Iron is a good conductor of electricity, as well as of magnetism, and whenever the magnetic lines in iron have motion relative to the iron itself, currents of electricity are produced in the iron. These are of course idle, useless currents and are wasted energy, tending only to heat the metal.

In practice, the production of eddy currents is greatly reduced by making the iron cores of transformers and dynamos of thin

sheets of metal, with the laminæ perpendicular to the path of the currents.

The eddy current loss depends therefore upon the degree of lamination, the thickness of the sheets, the insulation between them, the electrical resistance of the iron, the magnetic density and the frequency of the magnetic field.

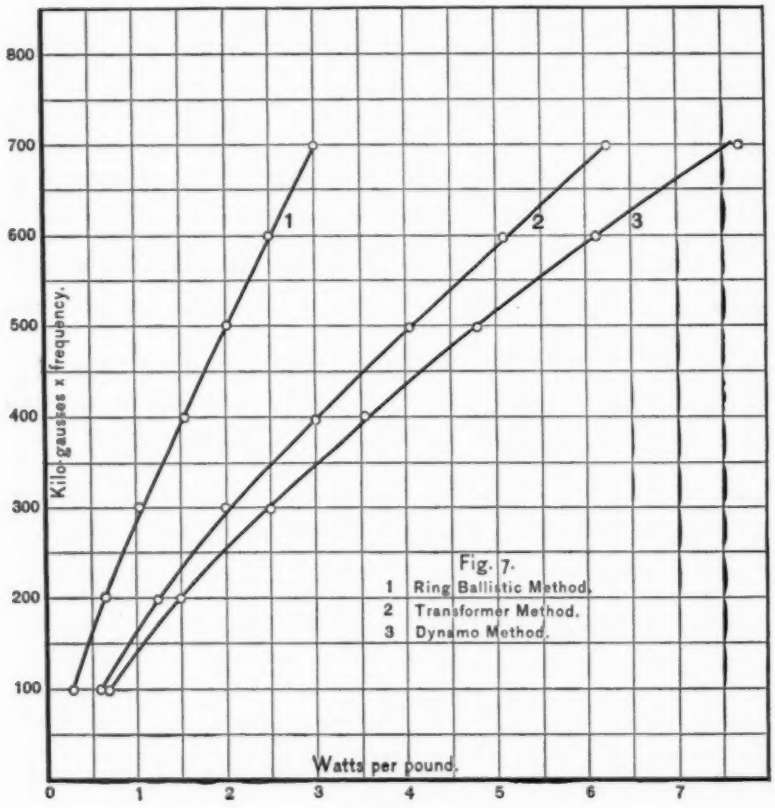


Fig. 7.
1 Ring Ballistic Method.
2 Transformer Method.
3 Dynamo Method.

It will be seen therefore that any method of testing sheet iron for core loss must duplicate as nearly as possible the conditions of actual use of the metal, or the results of tests will not check with tests of the finished machine.

Obviously the test must include both the hysteresis loss and the eddy current loss. The laminations or sheets should be pressed firmly together as in actual use.

The shape of the sample should be very much like that of a transformer core, if transformer iron is being tested, and should

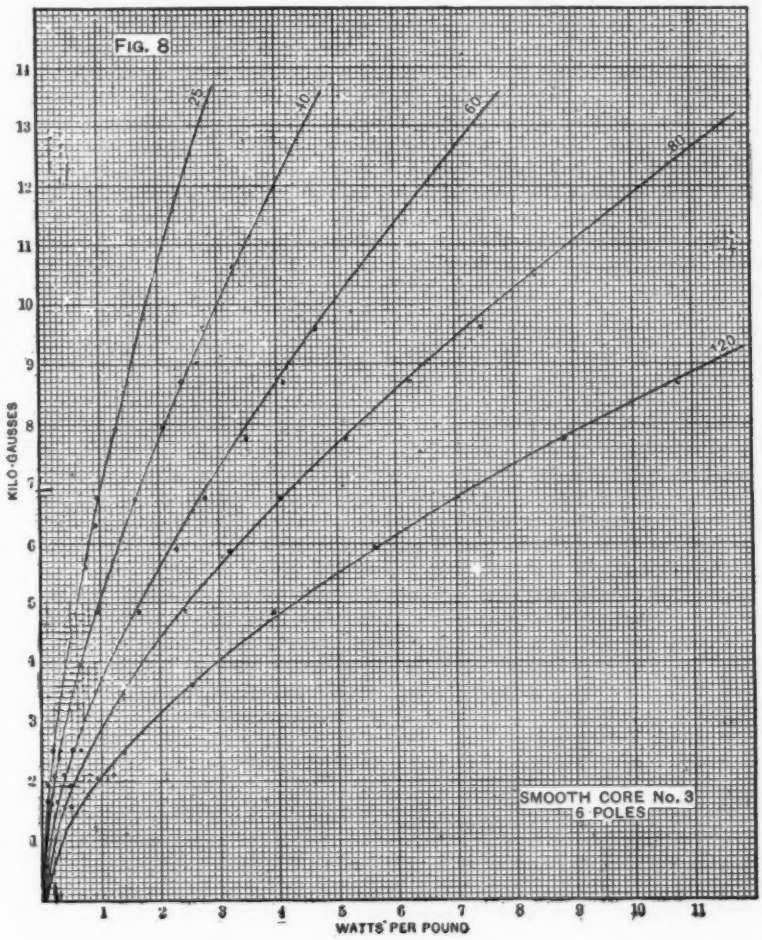


FIG. 8.

be magnetized by an alternating current of known frequency and wave form, and to a known density.

If armature iron loss is to be predetermined accurately, the specimen tested is magnetized by means of magnetized field poles, the relative motion of the magnetic field and the iron being pro-

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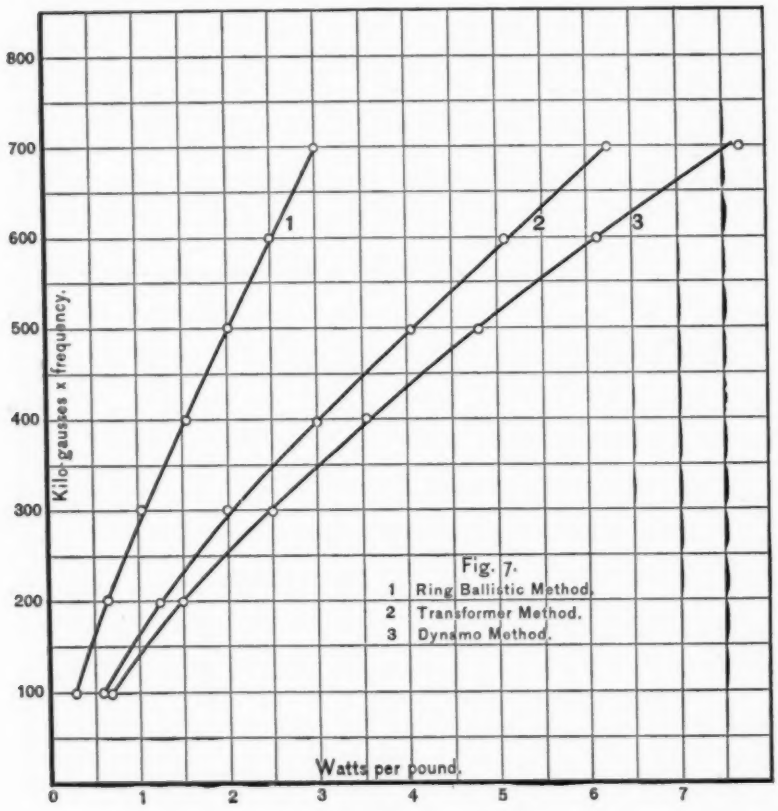

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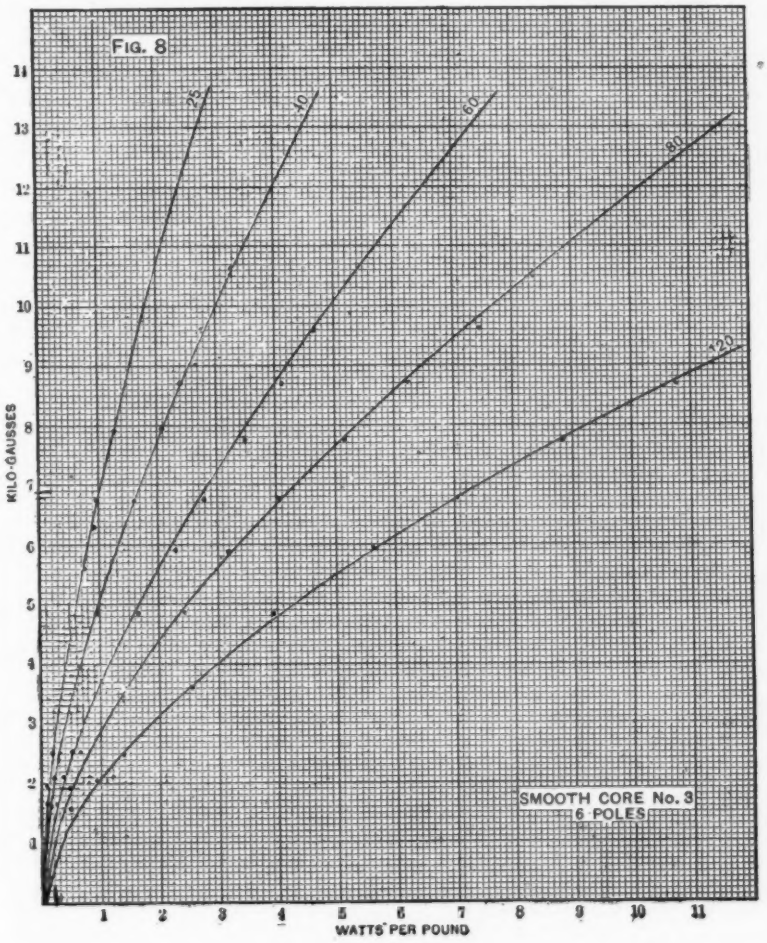


FIG. 8.

be magnetized by an alternating current of known frequency and wave form, and to a known density.

If armature iron loss is to be predetermined accurately, the specimen tested is magnetized by means of magnetized field poles, the relative motion of the magnetic field and the iron being pro-

duced by mechanical means. The frequency, and magnetic density should be known.

The author recently made a series of tests to compare the results on the same sample of sheet steel, when tested by different methods.

Method 1.—Calculation of hysteresis loss from the hysteresis loop. A number of sheet iron rings, 15 mils thick and about 5 in. inside diameter, 6 in. outside diameter, enough to stack ½ in. high were used, wound with several hundred turns of wire. Using a ballistic galvanometer, a hysteresis loop of the ring was obtained,

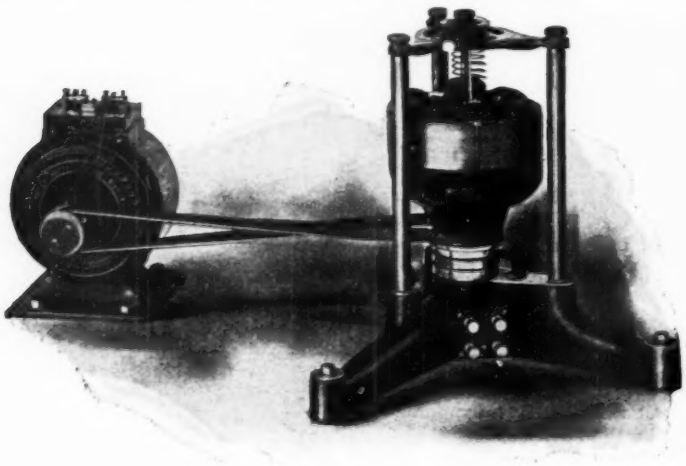


FIG. 9.

and from the area of the loop the hysteresis loss at different densities and frequencies was calculated.

Method 2.—Transformer wattmeter method. Using the same sample and winding, the coil was connected to a small variable speed alternator, through a specially devised, sensitive wattmeter.

The core was thus magnetized at various densities, for a number of different frequencies, the iron loss was obtained by subtracting the copper loss from the wattmeter reading, the remainder being the core loss.

Method 3.—Dynamo method. The ring was now unwound and the same discs tested in an apparatus similar to that illustrated in Fig. 9. In the first test the results are supposed to

exhibit hysteresis loss only. The equation by which the loss is calculated is imperical, although generally accepted as fairly accurate.

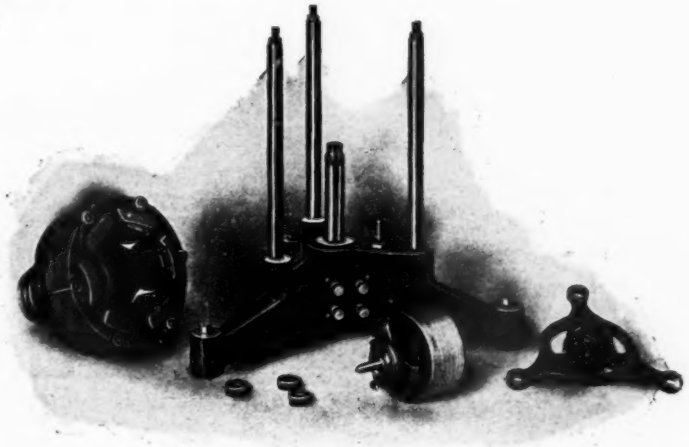


FIG. 10.

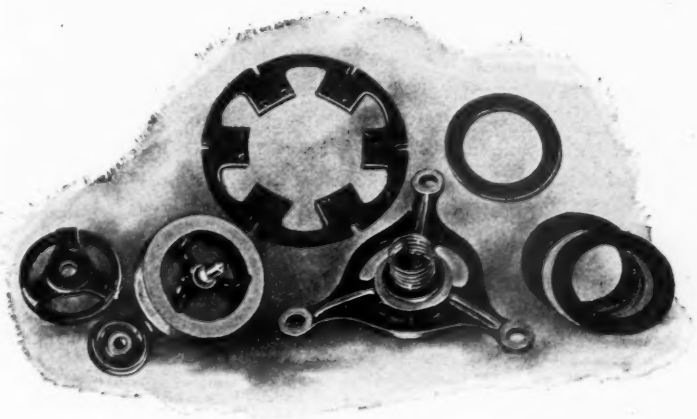


FIG. 11.

In the second case the iron formed the core of a small transformer, and was magnetized and tested just as transformer cores are tested.

In the third test the discs constituted the armature core of a

small generator, and were magnetized by the field poles of the machine.

To facilitate comparison the results of each test have been reduced to a single curve showing the relation between the loss in watts per pound of iron and the product of the magnetic density and frequency of magnetization, and are given in Fig. 7.

CORE LOSS METERS.

The apparatus for testing iron by the transformer wattmeter method was described in an article before this Society in 1903

FIG. 12.

(Vol. III, p. 288). It consists of a non-conducting shell which carries the transformer winding. The two halves of the shell, Fig. 12 are so arranged that the coil can be opened, the iron core inserted, and the turns of the coil restored by placing the two parts together.

An alternating current of constant value is used, the magnetizing force varied by changing the number of turns by means of a dial switch.

The resistance of the apparatus, whatever the number of turns, is constant, so that the C^2R loss is constant. The wattmeter is adjusted to read zero when the normal value of current is flowing and no iron core in the instrument. When the core is inserted and magnetized cyclically, the reading of the wattmeter is the core loss in the iron.

For determining the losses in iron due to cyclic magnetization

produced by pole pieces, the apparatus shown in Figs. 9, 10 and 11 is used. This apparatus consists of a revolving field, having six inwardly projecting poles. The field is rotated by means of a small motor, the speed of which can be varied to give different frequencies.

The specimen consists of a number of small stampings, which are placed on a brass spider. The shaft carrying the spider, rests on a jeweled bearing below, and is guided by a short cylindrical bearing at the top made of hardened steel.

When the field is rotated and energized by a current which passes into the coils through the collector ring, the core loss tends to cause the specimen to rotate with the field. It is prevented from rotating by a helical spring, one end of which is attached to the spider, and the other end to a milled head on the upper plate. A vertical pointer is mounted on the spider and a horizontal pointer is clamped above the milled head. The top plate is graduated into 240 divisions.

With no twist in the spring, and the vertical pointer at its zero, the horizontal pointer is set at zero on the scale. When the torque due to the core loss is balanced by turning the milled head the horizontal pointer indicates the core loss direct on the scale. The springs are made so that the instrument reads directly in watts at a stated frequency.

When desired the specimen used can be a standard armature stamping, so that there is no waste of material.

The air gap is of sufficient length to make the flux density in the specimen practically proportional to the current, so that the permeability of the specimen at the ordinary densities has very little effect on the density.

Using a light spring, a full scale deflection of one revolution gives 2.4 watts, one scale division representing .01 watts, making a setting readable to .001 of a watt.

This method of testing was suggested and used by Holden, who used a bipolar revolving field. Where two or three phase alternating currents are available, the field magnetism can be made to rotate, while the windings are stationary, but this has the disadvantage that the loss varies slightly with the wave form, and special apparatus is needed if tests are to be made at different frequencies.

METHODS OF TESTING CEMENTS FOR WATER-PROOFING PROPERTIES.

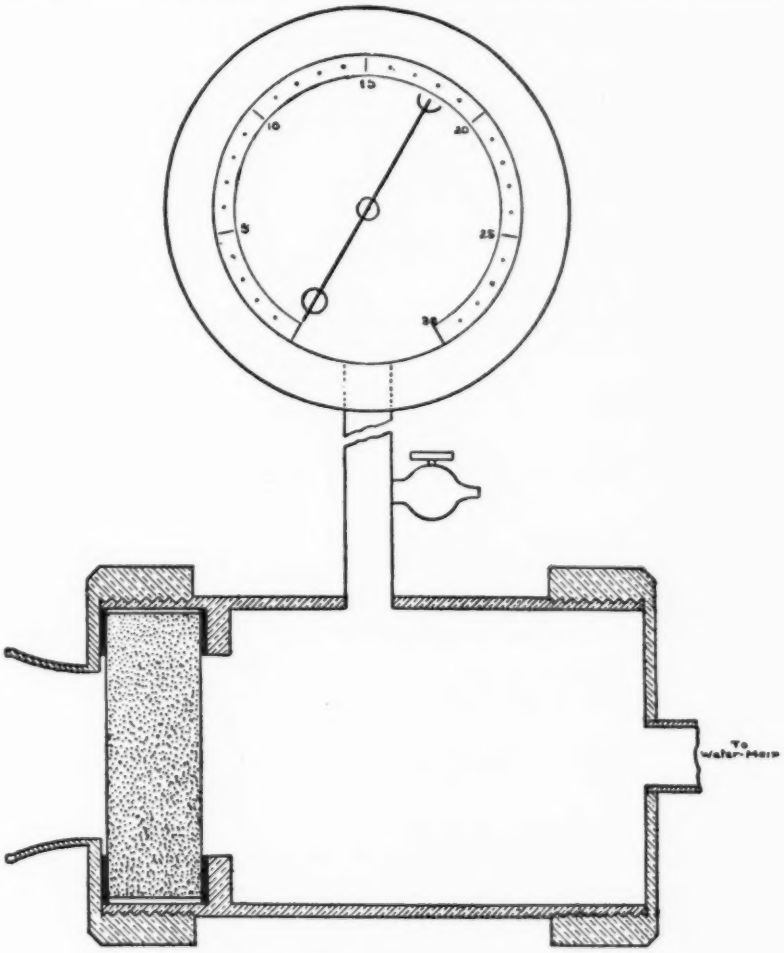
By W. Purves Taylor.

With the continually increasing scope of uses to which cement mortars and concretes are put, occasions frequently arise in which it is desired to make the construction waterproof so that it may resist either water under head or dampness and hence be entirely dry on the unexposed surface. To meet this condition several methods of waterproofing have been devised, which may be roughly divided into three classes—(1) methods involving the use of bituminous compounds with or without the addition of paper or felt, the waterproofing substances being distinct and separate from the concrete—(2) surface washes applied to the surface of the hardened concrete, and (3) compounds added to the cement or concrete in mixing and hence forming an intergral part of the concrete itself, it being with this last class that this paper is chiefly concerned. The many waterproofing compounds now in the market are so varied in character that it is extremely difficult to devise laboratory tests by means of which their suitability for construction may be determined, and furthermore it is most necessary that these compounds should be subjected to tests, for while some of them are based on sound principles and produce excellent results, others are so poor that placing them on the market is little short of arrant fraud.

It would appear that, to determine the resistance of a cement mortar to the action of water, the natural tests would be those of permeability and absorption, but unless the results of these tests be most carefully considered, misleading inferences are most likely to be drawn. Moreover simple as these tests are, there is no standard method of performing them, so that results obtained in different laboratories are seldom comparable.

In the pursuance of the investigations of these compounds in connection with the work of your Waterproofing Committee the first method of testing permeability tried was that recommended by the French Commission on Standard Methods of Testing, which consisted of cementing a glass tube on the top of a cube of

the cement mortar to be tested and then connecting this tube to a reservoir of water the height of which and hence the head of water acting in the tube being either $\frac{1}{10}$, 1, or 10 meters depending upon the permeability of the specimen. The writer was, however, unable



to obtain results anything like comparable or uniform by this method, although a number of variations in the size of the specimens as well as in the size and position of the tube were tried, and in spite of the fact that the greatest care was exercised in the forming and manipulation of the specimen.

After these unsatisfactory trials, the form of apparatus shown in the accompanying illustration was devised and has given more satisfactory results than any form so far experimented with. The specimen used is in the form of a disc three inches in diameter and one inch thick, which is made in a mold of spring steel fastened with a clamp or screw. The apparatus is made from a $3\frac{1}{4}$-inch brass pipe having a ring $\frac{1}{2}$ inch wide fastened 1 inch from the end of the pipe. Rubber packing $\frac{3}{16}$ inch thick is placed against this ring and also over the specimen so that by tightening the outer nut the test piece is securely locked into position. The orifice in the outer nut is 2 inches in diameter, while the pressure is indicated by a gauge under which is a pet cock through which the air can escape and by means of which the pressure is exactly regulated. For test—pieces of 1 : 3 mortar, the pressure of water should be 10 pounds, while the number of cubic centimeters of water per minute passing through the specimen gives a measure of the permeability.

In making permeability tests it is especially important that the manipulation of the specimen be uniform or otherwise most discordant results will follow, for it appears that permeability is more affected by small deviations of method than probably any other test to which cement is subjected.

Especial care should be taken to see that the granulometric composition of the sand is kept uniform, and the mixing and molding of the specimens should be performed with exceptional care. In the storage of the specimens there is no recognized standard practice although permeability is much affected thereby, storage in air increasing it, while storage in water decreases it, as the following example shows clearly, this test being made on a normal 1 : 3 Portland cement mortar—all tests on the same specimen:

Treatment.	Permeability.
7 days in water—14 days air	150 c. c. per minute.
48 hours more in water	133 " " " "
72 " " " "	127 " " " "
24 " " " air	133 " " " "
72 " " " "	172 " " " "
96 " " " "	200 " " " "
24 " " " water	163 " " " "
72 " " " "	150 " " " "

Another important factor affecting the results of the test is the time at which the reading is taken after the pressure has been

applied to the specimen, the rate of permeability first increasing for from 20 minutes to an hour and then slowly decreasing. The pressure of course must always be the same in any series of tests, the rate of flow varying approximately with the square root of the head.

In the test of absorption, there is comparative uniformity in practice except in regard to the treatment prior to immersion in water, some drying the specimen in an oven and others testing it merely air dry, the tests made in the first manner of course giving much greater values. Both methods of testing have strong arguments in their favor, but it is thought that tests on air dry specimens represent better the conditions of practice, and that their results indicate more nearly the true water resisting properties of the material.

Several other tests for waterproofing are occasionally made such as forming small bowls of the mortar and floating them in water, recording the time at which they sink, this test giving a measure of both absorption and permeability, but unfortunately not being capable of giving precise results and hence unsuited for a standard test, although well adapted to showing the comparative merits of any two mortars. Another test is made by spraying one side of a specimen or block from a standard nozzle and measurement being made of the time required for dampness to penetrate the face opposite the one on which the spray is applied, but such tests give practically no additional information when the absorption and permeability are known and are much less adaptable to standardization.

The following method has therefore been adopted tentatively as the standard for determining the water resisting properties of a cement mortar. Specimens are first made in accordance with standard practice in the shape of discs 1 in. in thickness and 3 in. in diameter, the mortar being made in the proportion of 1 : 3. The discs are kept in moist air 24 hours, then immersed in water six days and finally removed from the water and kept in dry air for 21 days more. At the end of this time (28 days from the time of making) they are weighed and placed in water for 48 hours then weighed a second time and the percentage of absorption determined. The specimens are then immediately placed in the permeability machine before they have commenced to dry out, and subjected to 10 pounds water pressure, which is maintained for

10 minutes, and then the number of c. c. of water passing in a minute are measured, giving the value for permeability. A test should be based on the results from not less than five specimens, any results being discarded which are obviously in error. Of course when it is expected to use the mortar under unusual conditions, these conditions should also be duplicated as nearly as possible on additional test pieces, and tests made on specimens kept in acid or alkaline waters, in oil, in gas drip, and in other conditions will give most valuable information.

To show the character of results obtained by this method, a few preliminary series of tests will be cited, the first being on mixtures of Portland and natural cement, the results of which follow, all tests being made on 1 : 3 mortars:

Mixture.		Strength.			Absorption.	Permeability.
Portland, per cent.	Natural, per cent.	7 days.	28 days.	4 mos.		
100	0	301	375	361	9.5	794
80	20	279	361	410	8.9	753
60	40	251	347	439	7.0	340
40	60	203	324	411	6.7	380
20	80	150	259	375	7.1	(500)
0	100	84	173	292	9.6	640

It will be observed that the absorption and permeability are both least when the mixture is about half and half, a result which might be expected. The high strength of these mixtures at four months presents also an interesting feature.

The following series shows a few tests made on mixtures of Portland cement and hydrated lime in 1 : 3 mixtures:

Mixture.		Strength.			Absorption.	Permeability.
Cement, per cent.	Lime, per cent.	7 days.	28 days.	4 mos.		
100	0	301	357	361	9.5	794
95	5	260	351	373	6.7	735
90	10	274	305	282	6.4	715
85	15	281	315	267	6.4	470
80	20	289	315	260	6.7	430
67	33	243	250	245	7.3	220
50	50	146	206	217	7.8	10

which shows the great value of the use of this material in decreasing permeability, while small additions have but little effect on the strength. The last values of absorption are apparently anomalous and may be due to error.

The value of the permeability tests was still better shown in the examination of cement mortars treated with various compounds the results of which will be presented later in the report of the Waterproofing Committee.

In closing, I would state that the purpose of introducing a discussion on this subject was due to the great difficulty experienced by the Committee in properly testing the various waterproofing compounds submitted for examination, and it was thought that an open discussion on these tests would not only be of interest to the members, but of help to the Committee in the pursuance of their investigations.

DISCUSSION.

Mr. Lazell. MR. E. W. LAZELL (by letter).—In connection with the paper on permeability tests of mortars by Mr. J. Purves Taylor, I wish to give some results obtained in the Laboratory of the Henry S.

TABLE I.

Lab. No.	Composition of Pat.	Age of Pat.	Water passing in c.c., time: 1 hr., pressure. 30 lbs.	Age of Pat.	Water passing in c.c., time: 1 hr., pressure: 30 lbs.
41,050	1 cement 3 sand	7 days	10 c.c.	28 days	.....
41,000	.95 cement .05 Limoid 3.00 sand	"	5 c.c.	"	.....
41,070	.90 cement .10 Limoid 3.00 sand	"	4 c.c.	"	.....
41,080	.85 cement .15 Limoid 3.00 sand	"	2 c.c.	"	.....
41,090	.80 cement .20 Limoid 3.00 sand	"	5 c.c.	"	.....
43,490	1 cement 4 sand	28 days	495 c.c.	42 days*	10
43,500	.95 cement .05 Limoid 4.00 sand	"	.....	" *	.....
43,510	.90 cement .10 Limoid 4.00 sand	"	.....	" *	.....
43,520	.85 cement .15 Limoid 4.00 sand	"	.....	" *	.....
43,530	.80 cement .20 Limoid 4.00 sand	"	.....	" *	.....

* Note in these tests the same pats were used as in the twenty-eight day test, with the exception that they were allowed to dry out in the atmosphere of the laboratory for two weeks before being retested.

Mr. Lazell.

Spackman Engineering Company in testing pats composed of cement sand mortar and cement hydrated lime sand mortar. The pats were made up in circular brass molds, three inches in diameter and one inch thick and were tested in an apparatus similar to that used by Mr. Taylor. The water pressure employed was thirty pounds and each pat was exposed to this pressure for one hour and the water coming through the pat was measured.

The sand used in these tests was standard Ottawa sand; the test pieces were stored twenty-four hours in a moist closet and then kept in the regular briquette tanks, under water, until tested. For each test five pats were made up, two being tested at the age of seven days and two at twenty-eight days; the results given are the average of two pats.

The Portland cement used was a normal Portland cement, and was thoroughly tested before use; the lime employed was Limoid, a hydrated dolometic lime supplied by the Charles Warner Company, the addition of Limoid in each instance replaces the same amount of cement. Table I gives the results obtained.

The results show that the addition of hydrated lime to cement mortars increased their resistance to the flow of water through it.

It may be interesting to give the results obtained from the tensile tests on the 1 to 3 mortars with the various lime additions. These briquettes were made up in the regular manner, stored twenty-four hours in a moist closet and then kept in the regular briquette tanks until broken; the tests cover a period of nine months:

1–5 TESTS. NINE MONTHS. WATER EXPOSURE.

	1 P. C. 3 Sand.	.95 P. C. .05 L. 3 Sand.	.90 P. C. .10 L. 3 Sand.	.85 P. C. .15 L. 3 Sand.	.80 P. C. .20 L. 3 Sand.	.75 P. C. .25 L. 3 Sand.	.70 P. C. .30 L. 3 Sand.
Lab. No.	39,890	40,310	40,370	40,430	40,490	41,620	41,740
7 days	206	157	189	239	237	173	175
28 days	278	311	364	264	268	259	268
3 months	441	389	419	372	374	314	281
6 months	358	321	341	278	260	207	253
9 months	390	301	308	279	268	250	232

WORK DONE IN THE STRUCTURAL MATERIALS TESTING LABORATORIES, UNITED STATES GEOLOGICAL SURVEY, DURING THE YEAR ENDING JUNE 30, 1906.

By Richard L. Humphrey.

The work done in the Structural Materials Testing Laboratories, United States Geological Survey, from July 1, 1905 to July 1, 1906, consisted of tests of the constituent materials of mortar and concrete.

Sands, gravels, broken stone, cinders and slags from various localities throughout the country were tested for their suitability and value for use in mortar and concrete.

In order to obtain a uniform basis of comparison for the various tests ten barrels of Portland cement (donated by each of seven manufacturers) were thoroughly mixed and the resulting mix, called "typical Portland cement," was used in all these investigations.

Seven barrels, one barrel of each brand, were mixed together at one time and placed in galvanized iron cans. Although the cans were sealed as soon as filled with this mixture it was thought best, since the tests would extend over a long period of time, to parallel all mortar tests of sands by a series of neat tests in order to ascertain whether there would be any deterioration in the quality of the cement.

Samples were taken from each barrel before mixing, from the resulting mix, and again when the cans were unsealed for tests of physical strength and chemical composition. No variation in strength or quality was noticed.

All tests of cement were made in accordance with the methods recommended by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers.

Tests of neat cement were made for tensile, compressive and transverse strength for 1, 7, 28, 90, 180 and 360 days, and a parallel series of tests was made of one to three mortar for all

ages except one day. Standard Ottawa sand was used in all mortar tests to determine the quality of the "typical cement."

A chemical analysis was made of each sample in accordance with the methods recommended by the Committee of the New York Section of the Society for Chemical Industry.

The following general conclusions are noticeable: For cements yielding a tensile strength of less than 600 pounds at seven days the increase of strength from seven to twenty-eight days was 42 per cent.; while those for which the tensile strength fell between 600 and 700 pounds at seven days the average increase was 12 per cent., thus showing a decrease of relative gain as the strength at seven days increases.

In the case of one to three mortars the increase of tensile strength between seven and twenty-eight days was as follows:

Tensile strength at 7 days.	Percentage increase from 7 to 28 days.
Below 200 lbs	86.2
200 to 250 lbs	74.6
250 to 300 "	36.6
300 to 350 "	20.6

Thus, again showing a falling off in relative gain as the strength at seven days increases.

The ratio of compressive to tensile strength for neat cement varied from 7½ at seven days to 12½ at six months, while for 1 to 3 mixtures with Ottawa sand this ratio varied from 4 at seven days to 6.4 at six months. The ratio of transverse to tensile strength was about 1.92.

The probable error of the mean of ten determinations for tensile tests was about 1.1 per cent., while the average probable error of a single determination was about 3 per cent. The probable error of mortar tests was about the same.

Thirty-six samples of sand were collected by a geologist who made complete reports upon the location, extent, and geological formation of the source of the supply, the methods of preparing material for the market, markets supplied, output, etc.

All sands were investigated as to specific gravity, weight per cubic foot as received and after drying, mechanical analysis using Nos. 10, 20, 30, 40, 50, 80, 100 and 200 sieves, percentage and character of silt, percentage of voids, percentage of moisture in the

sample as received, and strength in tension, compression and bending with different proportions and different size of grains.

The results of the strength tests studied in connection with the corresponding mechanical analysis seems to indicate that the curve which nearly approaches a straight line gives the greatest strength, and that the result of the yield test for density is a much better criterion of the strength than the percentage of voids, the increase in strength with increase in density being much more consistent. For 90 days the compressive strength of 1 to 3 mortar from unscreened sand varied from 2,000 to 6 200 lbs.; for 1 to 4 mortar from unscreened sand from 1,500 to 4,500 lbs.; and for 1 to 3 mortar from sand screened between Nos. 20 to 30 sieves from 1,500 to 3,200 lbs. per square inch.

The tensile strength for the same period varied from 370 lbs. to 745 lbs. for 1 to 3 unscreened sand mortar; from 270 to 660 lbs.; for 1 to 4; and 290 to 495 lbs. for 1 to 3 sand, screened between Nos. 20 to 30 sieves.

The percentage of voids in the unscreened sand had little influence on the strength of the 20–30 material screened from it; when the voids in the unscreened sand was small the strength of the 1 to 4 mortar was higher than that of the 1 to 3 mortar from 20–30 sand. As the voids in the unscreened sand increased the strength of the 1 to 4 mortar fell steadily with respect to the 1 to 3 mortar of 20–30 sand, until with sands having 40 per cent. of voids the latter resulted in a stronger mortar than the former, and even approached the 1 to 3 mortar from unscreened sand.

The ratio of compressive to tensile strength is practically the same for mixtures of 1 to 3, 1 to 4 unscreened and 1 to 3 (20–30) sand varying from 4½ at seven days to 9 at six months.

The ratio of this modulus of strength in bending to the tensile strength is also fairly constant for all mixtures being about the same (1.8) at seven days and six months.

Sand screened (passing ¼ inch screen) from twelve samples of gravel was also tested and the results of the strength and density tests and mechanical analysis led to conclusions similar to those for natural sands except that the ratio of the compressive to the tensile strength varied from 8 at seven days to 11 at six months. The sand screened (passing ¼ inch screen) from broken stone yielded the same general results as the sand from the gravels.

Thirty-six (36) samples of broken stone and of gravel were investigated for specific gravity, mechanical analysis using screens with 2, 1½, 1¼, 1, ¾, ½, and ¼ inch mesh, and sieves Nos. 10, 20, 30, 40, 50, 80, 100 and 200; weight per cubic foot, as received and after drying; absorption; percentage of voids; amount and character of silt; yield; and strength.

The results of the tests of the material finer than ¼ inch have already been referred to. The tests of the material larger than ¼ inch are not yet in shape for presentation.

These tests of constituent materials of mortar and concrete will be continued on a much more extensive scale made possible by the increased equipment. In addition to these tests investigations were carried on in a few of the laboratories connected with Engineering Schools. The test pieces were made and tested in the presence of a representative of the Structural Materials Testing Laboratories. The results of these tests are being collated and will be published in a Bulletin.

There is also being planned the largest series of tests of concrete beams, plain and reinforced, about 600 in all, that has yet been undertaken. The variables in this series are percentage of reinforcement, size and number of rods, aggregate and age.

Auxiliary tests of the materials of which the beams are composed and strength tests of the concrete will also be made.

An elaborate series of tests of concrete blocks of different types in which the proportions, consistencies, and method of curing are to be varied will also be made.

It is expected that much information of value will be secured during the coming year.

CONCRETE COLUMN TESTS AT THE WATERTOWN ARSENAL.

By James E. Howard.

Tests on cements, mortars, and concretes, which have been in progress during the past six years at the Watertown Arsenal, have reached the subject of columns. Of these, ninety-nine have been tested, others have been made and await being tested, while still others of the series are yet to be made.

The tests embrace columns of different mixtures, ranging from neat cement to those of very lean mixtures, both plain and reinforced with longitudinal bars imbedded therein, or by the several current methods of external lateral reinforcement, consisting of hoops and other means, and also by the combined action of hoops and longitudinal bars. Reinforcing material has been received from the Expanded Metal Companies, The Hennebique Construction Company, The Trussed Concrete Steel Company, The Cummings Structural Concrete Company, and the Clinton Wire Cloth Company.

In general, the dimensions of the columns are 8 feet in height and from 10 inches to 12 inches in diameter. They are made in molds, excepting a number of those having expanded metal cages which were covered with finer mesh lathing, in a vertical position, of wet mixtures, and harden in the air.

They are tested in a horizontal position. For purposes of transportation, adjustment in the testing machine, and to secure even bearing surfaces, they are built upon iron plates and capped with the same. Side rods with turnbuckles are used to put the columns under sufficient initial compression to permit of being handled.

During testing the columns are loaded with increments of 50 pounds per square inch, measuring the amount of compression under each increment, returning to the initial load and observing the sets. Micrometer observations are thus made on a gauged length of 50 inches, equi-distant from the ends of the columns.

Acknowledgement is made to the *Railway and Engineering Review* for the cuts used in the paper.—Ed.

Full details are published in Tests of Metals, a Congressional document, issued by the Ordnance Department, U. S. Army.

The following tables give the principal features of tests which have been made since the last published report, of 1905. These results, in detail, will appear later in Tests of Metals, 1906.

In presenting tests reaching up to the time of this meeting, necessarily little opportunity has been available for comparisons and deductions. Indeed, since the series is by no means completed, extended deductions should be held in abeyance. Certain features of interest, however, have been developed and will be referred to, for the illustration of which a number of diagrams have been prepared.

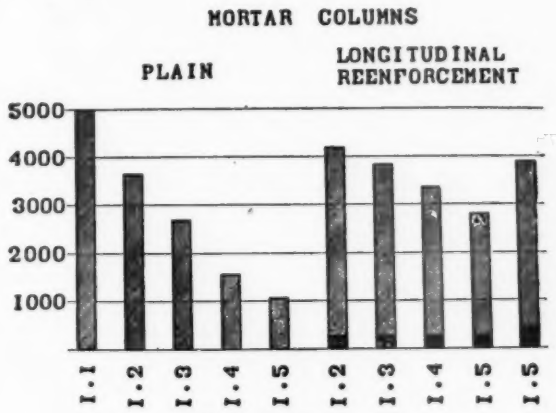


Diagram No. 1.

On diagram No. 1 are represented the compressive strengths of some mortar columns, plain and reinforced with longitudinal bars of $\frac{3}{4}$-inch twisted steel. The progressive loss in strength of the plain columns, as the mixtures become leaner, will be noted. The ultimate strength of the 1:1 column was not reached. It exceeded the capacity of the testing machine. This mixture was not reinforced. Each of the others were reinforced, four with 8 bars each and one with 13. The percentage of reinforcement was about 2.86 and 4.63, the darker shaded lower ends of the figures representing the relative amounts.

The steel reinforcing bars extended from end to end of the columns, and came to a full bearing against the compression

platforms of the testing machine. They were used without other lateral support than that which was afforded by the mortar in which they were imbedded. These reinforced columns would be classified as strong columns, according to current practice.

Diagram No. 2 shows the strength of a rich and a lean mortar, each of which was reinforced with hoops and longitudinal angle bars; also, corresponding concretes, reinforced. The hoops measured 1.5 in. by 0.12 in. in cross section, lapped and riveted joints. The plain 1 : 1 mortar displayed a compressive

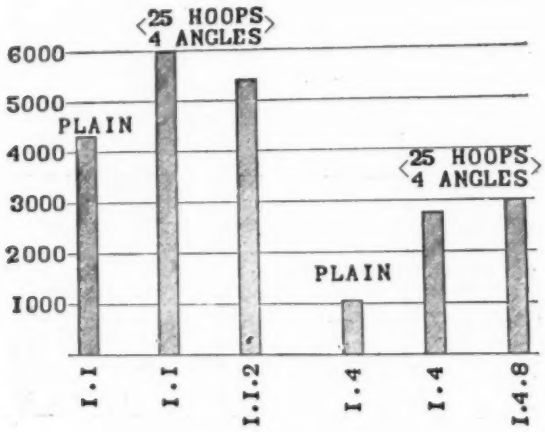


Diagram No. 2.

strength of 4,320 pounds per square inch, which in the hooped column rose 5,980 pounds. The addition of two parts trap rock to this mortar resulted in a strength of 5,433 pounds. This loss in strength, by the addition of stone to a mortar, is not peculiar to the present example. It has occurred in a number of cases.

The weaker 1 : 4 mortar was raised by the hooping and angles from 1,050 pounds to 2,766 pounds, which in the corresponding concrete reached an ultimate strength of 3,002 pounds. The free span between the hoops, 2½ inches, permitted this lean mortar to flake off, while the larger pieces of stone in the concrete were retained in place.

On the diagram which next follows, No. 3, the several columns were of the same composition, namely, 1 : 2 : 4 mixtures.

This diagram is intended to illustrate the effect of hooping alone, and with the further reinforcement of longitudinal angle bars. The compressive strengths of this group are as follows:

	Lbs. per sq. in.
Plain column	1,413
13 hoops	2,232
13 hoops and 4 angle bars	3,029
25 hoops	3,428
25 hoops and 4 angle bars	4,189
47 hoops	5,289

Thus it appears that the hoops and angles each contribute toward increasing the ultimate strength of the columns.

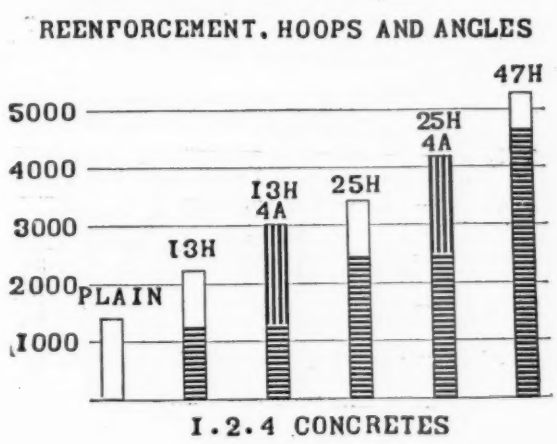


Diagram No. 3.

The question of ultimate strength only is now referred to, considering the gain effected by means of lateral reinforcement. It will be shown presently that rigidity of shape does not advance in corresponding degree with the gain in compressive strength. This is regarded as an important feature, not to be overlooked in judging of the advantages of exterior lateral support as compared with longitudinal reinforcement, or the gain in both strength and rigidity which accompanies the use of rich cement mixtures. Any desired strength may be attained by means of lateral reinforcement, if sufficient metal is used, but it is obvious that a certain amount of longitudinal compression of the concrete will

be necessary before the lateral reinforcement becomes effective, which, in the case of lean mixtures, involves a large direct compressive movement of the column.

On diagram No. 4 are represented several columns which are strong by reason of their composition or on account of their reinforcement. In composition, reinforcement, and strength, they are described as follows:

	Lbs. per sq. in.
1 : 1 mortar, plain	above 5,011
1 : 1 : 2 concrete, plain	3,900
1 : 2 mortar, 8, ¾ in. twisted steel bars	4,200
1 : 5 mortar, 13, ¾ in. twisted steel bars	3,905
1 : 2 : 4 concrete, 25 hoops and 4 angle bars	4,189
1 : 3 : 6 concrete, 25 hoops and 4 angle bars	3,862
1 : 4 : 8 concrete, 25 hoops and 4 angle bars	3,002

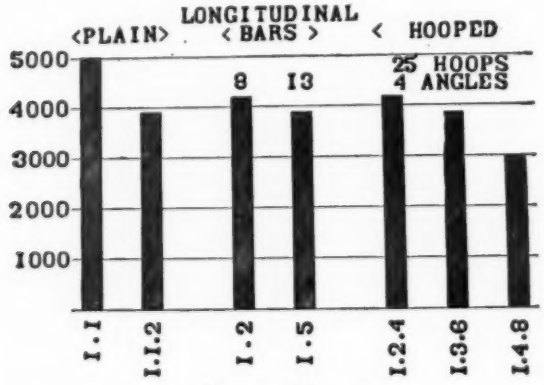


Diagram No. 4.

The relative rigidity of these columns, a feature not suggested by a comparison of their compressive strengths, is indicated on diagram No. 5, which next follows.

The order in which the compression curves appear is the same as the figures on diagram No. 4, excepting the 1 : 1 mortar and the 1 : 1 : 2 concrete have changed places, the latter appearing first on the left of this group.

As may be noted, the plain columns display the greatest rigidity of the several types here represented. This has been a noticeable feature in the tests as a whole.

It is even found that plain columns are a little more rigid, over the range of stresses here plotted, than the same mixtures in which longitudinal bars are used as the means of reinforcement. In so many cases has this occurred that some explanation should be sought why the presence of the steel bars, themselves so much more rigid than the concrete, should not result in increased rigidity of the column as a whole. It is not improbable that the settlement in height of the column is so far restricted by the steel bars that minute fissures are developed during the

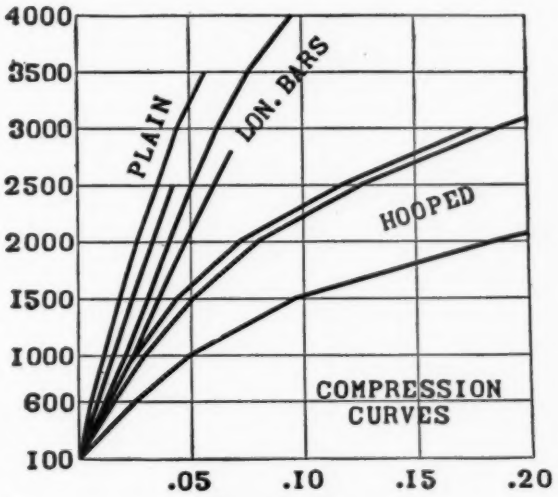


Diagram No. 5.

early stages of hardening of the concrete. Internal strains without the presence of fissures, would hardly account for this behavior.

The difference between the plain and the longitudinally reinforced columns is not great, however, in this respect.

The hooped columns are a distinct group, and decidedly more compressible than the others. Comparisons are now being made between columns of different mixtures, and, it may be added the leanest mixtures are expected to display the greatest compressibility. However, lateral reinforcement, while effective in raising the ultimate strength for loads once applied, does not result in imparting rigidity to a weak concrete. The value of lateral reinforcement, as a method of raising the limit of endur-

ance against long continued or repeated stresses, is a query suggested by an inspection of these curves.

Diagram No. 6 is introduced merely to show the range in compressibility which is experienced, and the sets developed, in different mixtures. The several curves refer to hooped columns, excepting the 1 : 1 mortar. They are plotted because of their greater strength over the plain mixtures, but the curves are similar in their characteristics.

The moduli of elasticity at successive stages, referring to values over a range of 500 pounds per square inch next above the

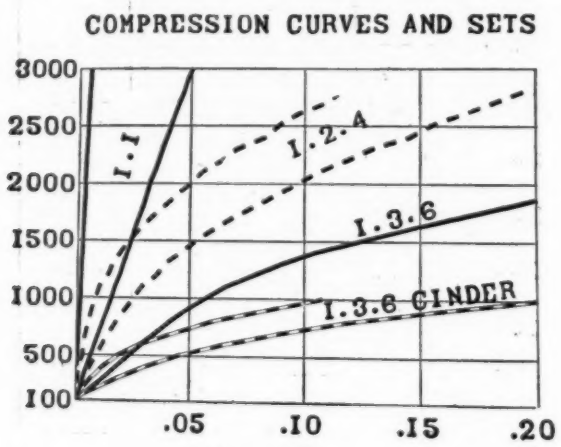


Diagram No. 6.

initial load, are shown on diagram No. 7. In obtaining these values the columns were loaded with successive higher stresses and then returned to the range from 100 to 600 pounds, at which time the micrometer observations were made. The numerical values were as follows:—

1 : 1 mortar, plain.

	Lbs. per sq. in.
Original value of E	3,378,000
After a load of 1,000 lbs.	3,247,000
" 1,500 "	3,247,000
" 2,000 "	3,205,000
" 2,500 "	3,165,000
" 3,000 "	3,086,000
" 3,500 "	3,086,000

1 : 2 : 4 concrete, 25 hoops.

	Lbs. per sq. in.
Original value of E	2,874,000
After a load of 1,000 lbs.	2,551,000
" 1,500 "	2,016,000
" 2,000 "	1,582,000
" 2,500 "	1,337,000
" 2,800 "	1,244,000

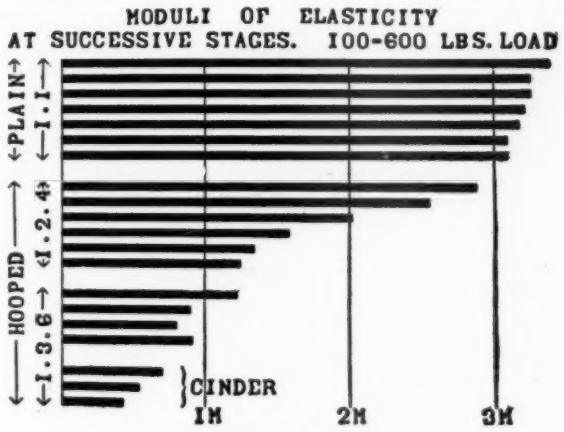


Diagram No. 7.

1 : 3 : 6 concrete, 48 light hoops, 4 angle bars.

	Lbs. per sq. in.
Original value of E	1,220,000
After a load of 1,000 lbs.	899,000
" 1,500 "	801,000
" 2,000 "	912,000

1 : 3 : 6 concrete, cinder, 25 hoops.

	Lbs. per sq. in.
Original value of E	702,000
After a load of 850 lbs.	538,000
" 1,000 "	426,000

Neat cement and rich mortars do not show any considerable loss in the value of the modulus of elasticity when examined over an early range of loads succeeding the application of successively higher stresses.

Other mixtures are subject to decided changes. After the

application of each higher load there results a difference in the rate of compressibility under lower stresses, the modulus in some instances dropping to less than one-half its original value. It will be understood from this that the proportion of load carried by steel in combination with concrete is subject to great fluctuations. This feature will deserve consideration in the case of reinforced beams, when they are studied in the manner in which the present column tests are being carried out.

It may be remarked in passing that compressive stresses exceeding 50,000 pounds per square inch are of frequent occurence in columns tested to their ultimate resistance, whence it

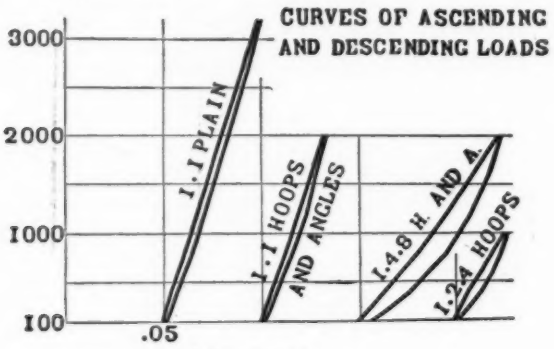


Diagram No. 8.

follows that steel employed for longitudinal reinforcement should have an elastic limit not less than the above.

In addition to the changes in the modulus above referred to, the curves of ascending and descending stresses do not coincide, the departure increasing with the application of successively higher loads. This behavior is indicated upon diagram No. 8, which shows the stress-strain curves of four columns.

These curves were obtained after the columns had been loaded as follows:

	Lbs. per sq. in.
1: 1 mortar, plain, after having been loaded with	3,500
1: 1 mortar, 25 hoops and 4 angle bars, after having been loaded with	5,700
1: 4: 8 concrete, 25 hoops and 4 angle bars, after having been loaded with	2,500
1: 2: 4 concrete, 25 hoops, after having been loaded with .	3,200

CONCRETE AND MORTAR COLUMN TESTS AT WATERTOWN ARSENAL
COLUMNS 8 FT HIGH- TABLE NO. I.

No. of Test.	Diameter of Column.	Composition				Age		Reenforcing Metal.	Gross Sectional Area.	Weight of Concrete or Mortar per cu. ft.	Compressive Strength	
		Cement	Sand	Stone or Cinder	Kind of Stone or Cinder						Total.	Per Sq. Inch.
	Inches					Mos.	Days		Sq. Inch.	Pounds	Pounds	Pounds
1718	12.35	1	2	4	3/4" to 1 1/2" Trap Rock.	5	8	2" Mesh Wire Cage	119.79	149.6	268,538	2,200
1722	12.25	1	2	4	"	5	13	3"- " " "	117.86	151.3	242,000	2,053
1724	12.45	1	2	4	"	5	13	"	121.74	149.4	318,000	2,610
1720	12.25	1	3	6	"	5	8	2" Mesh Wire Cage	117.86	150.1	159.111	1,350
1719	12.45	1	3	6	"	5	8	"	121.74	145.7	168,000	1,380
1721	12.40	1	3	6	"	5	8	"	120.76	143.1	183,500	1,520
1723	12.34	1	3	6	"	5	12	3" Mesh Wire Cage	119.60	147.6	197,340	1,650
1725	12.35	1	3	6	"	5	11	"	119.79	149.6	206,000	1,720
1734	10.40	1	1	0	None	6	11	None	*84.95	132.6	367,000	4,320
1735	10.40	1	1	0	"	6	12	25-1 1/2" Hoops & 4-Angles	84.95	132.6	508,000	5,980
1730	10.45	1	1	2	3/4" to 1 1/2" Trap Rock.	5	0	"	85.77	149.1	466,000	5,433
1736	10.38	1	4	0	None	6	8	None	84.62	118.7	88,851	1,050
1737	10.40	1	4	0	"	6	8	25-1 1/2" Hoops & 4-Angles	84.95	119.9	235,000	2,766
1733	10.40	1	4	8	3/4" to 1 1/2" Trap Rock	6	11	"	84.95	146.6	255.000	3,002
1731	10.40	1	2	4	"	5	16	None	84.95	150.0	120.000	1,413
1740	10.38	1	2	4	"	6	6	13-1 1/2" Hoops	84.62	149.2	188.900	2,232
1741	10.38	1	2	4	"	6	5	25-1 1/2" Hoops	84.62	148.6	290,100	3,428
1739	10.35	1	2	4	"	6	6	47-1 1/2" Hoops	84.13	149.4	445,000	5,289
1738	10.38	1	2	4	"	6	7	13-1 1/2" Hoops & 4-Angles	84.62	150.7	256 300	3,029
1692	10.40	1	2	4	"	0	15	25-1 1/2" Hoops & 4-Angles	84.95	144.2	260,400	3,065
1726	10.30	1	2	4	"	5	12	"	83.32	150.7	349,000	4,189
1728	12.00 *	1	2	4	"	5	12	"	113.10	149.4	370,000	3,271
1746	10.36	1	2	4	1/4" to 3/4" Trap Rock	5	12	48-1" Hoops & 4-Angles	84.30	147.2	324,000	3,843
1744	11.95 *	1	2	4	"	6	0	"	112.16	148.2	335.200	2,989
1732	10.38	1	3	6	3/4" to 1 1/2" Trap Rock	5	11	None	84.62	148.2	63,465	750
** 1742	10.38	1	3	6	"	6	4	25-1 1/2" Hoops	84.62	145.9	162,300	1,918
1743	10.38	1	3	6	Cinders	6	4	"	84.62	101.3	96,000	1,134
1727	10.35	1	3	6	3/4" to 1 1/2" Trap Rock.	5	11	25-1 1/2" Hoops & 4-Angles	84.13	148.3	325,000	3,836
1729	12.02 *	1	3	6	"	5	3	"	113.47	144.6	299,000	2,634
1747	10.36	1	3	6	1/4" to 3/4" Trap Rock.	5	11	48-1" Hoops & 4-Angles	84.30	138.9	212,000	2,515
1745	11.95 *	1	3	6	"	5	13	"	112.16	142.2	259.000	2,309
1714	12.00	1	2	4	3/4" Trap Rock.	5	11	3-Kahn Bars & 11-Hoopes	113.10	145.4	265,500	2,350
1717	12.00	1	2	4	"	5	8	"	113.10	145.6	237,510	2,100
1712	12.45 x 12.47	1	2	4	"	5	11	4-Kahn Bars & 11-Hoopes	155.25	143.4	279,450	1,800
1713	12.45 x 12.47	1	2	4	"	5	11	"	155.25	144.6	394,000	2,538
1716	12.48 x 12.49	1	2	4	"	5	10	"	155.88	143.8	296,172	1,900
1715	12.45 x 12.49	1	2	4	"	5	10	4-Truscon Bars & 11-Hoopes	155.50	145.8	367,500	2,363
1705	12.02	1	3	6	3/4" to 1 1/2" Trap Rock.	5	5	None	113.47	146.1	164,100	1,446
1706	12.02	1	3	6	3/4" to 1 1/2" Pebbles	5	3	"	113.47	128.0	143,000	1,260
1707	12.00	1	3	6	Cinders	5	0	"	113.10	101.4	78,900	698

* Exterior Shell.
** Column No. 1742 was defective:- One hoop was displaced during construction:-

CONCRETE AND MORTAR COLUMN TESTS AT WATERTOWN ARSENAL.
COLUMNS 8FT HIGH:- TABLE - NO. 2.

No. of Test.	Brand of Cement.	Sectional Area. Gross.	Sectional Area. Concrete or Mortar.	Sectional Area. Longitudinal Bars.	Metal in Longitudinal Bars of Column.	Description of Reenforcement.	
		Sq. Ins.	Sq. Ins.	Sq. Ins.	%		
1718	Alpha	119.79	119.79	None		2" mesh steel wire cage. 48 Circular wires .104" diameter, electrically welded ends; 19 longitudinal wires .104" diameter, electrically welded intersections.	Electrically welded ends and intersections.
1722	"	117.86	117.86	"		3" mesh steel wire cage. 33 Cir. & 13 long. wires, each .104" diameter.	
1724	"	121.74	121.74	"		3" mesh steel wire cage. 33 Cir. .145" diameter wires; 13 longitudinal .104" diam. wires.	
1720	"	117.86	117.86	"		2" mesh steel wire cage. 49 Cir. .104" " " 19 " " " "	
1719	"	121.74	121.74	"		2" mesh steel wire cage. " .144" " " " " " " " "	
1721	"	120.76	120.76	"		2" mesh steel wire cage. " " " " " " " " " "	
1723	"	119.60	119.60	"		3" mesh steel wire cage. 33 cir. & 13 longitudinal .104" diameter wires.	
1725	"	119.79	119.79	"		3" mesh steel wire cage. 33 cir. .145" diam. wires; 13 longitudinal .104" diameter wires.	
1734	"	84.95	84.95	"		None	
1735	"	84.95	84.04	.91	1.07	25-hoops $1\frac{1}{2}$" wide by .12" thick by 10" inside diameter, and 4-steel angle bars each 1"x1"x$\frac{1}{8}$".	
1730	"	85.77	84.86	.91	1.06	"	
1736	"	84.62	84.62	None		None	
1737	"	84.95	84.04	.91	1.07	25-hoops $1\frac{1}{2}$" wide by .12" thick by 10" inside diameter, and 4-steel angle bars each 1"x1"x$\frac{1}{8}$".	
1733	"	84.95	84.04	.91	1.07	"	
1731	"	84.95	84.95	None		None	
1740	"	84.62	84.62	"		13-Hoops $1\frac{1}{2}$" wide by .12" thick by 10" inside diameter.	
1741	"	84.62	84.62	"		25- " " " " " " " " " "	
1739	"	84.13	84.13	"		47- " " " " " " " " " "	
1738	"	84.62	83.71	.91	1.08	13- " " " " " " " " " " & 4-Steel angle bars each 1"x1"x$\frac{1}{8}$".	
1692	"	84.95	84.04	.91	1.07	25- " " " " " " " " " " " " " " " " " "	
1726	"	83.32	82.41	.91	1.09	"	
1728	"	113.10	112.19	.91	0.80	"	
1746	"	84.30	83.39	.91	1.08	48-hoops .104" wide by .6" thick by 10" inside diameter, and 4-Steel angle bars each 1"x1"x$\frac{1}{8}$".	
1744	"	112.16	111.25	.91	0.81	"	
1732	"	84.62	84.62	None		None	
1742	"	84.62	84.62	"		25-Hoops $1\frac{1}{2}$" wide by .12" thick by 10" inside diameter.	
1743	"	84.62	84.62	"		"	
1727	"	84.13	83.22	.91	1.08	25-Hoops $1\frac{1}{2}$" wide by .12" thick by 10" inside diameter. & 4-Steel angle bars each 1"x1"x$\frac{1}{8}$".	
1729	"	113.47	112.56	.91	0.80	"	
1747	"	84.30	83.39	.91	1.08	48-Hoops .106" wide by .06" thick by 10" inside diameter, and 4-Steel angle bars each 1"x1"x$\frac{1}{8}$".	
1745	"	112.16	111.25	.91	0.81	48-Hoops .104" " " " " " " " " " " " " " " " " "	
1714	"	113.10	111.37	1.73	1.53	3-Kahn bars, .76" x .76" stems, with prongs bent inward at angle of 45° to axis.	embraced by 11 hoops of $\frac{3}{8}$" wire.
1717	"	113.10	111.37	1.73	1.53	3- " " " " " " " " " " " " " " " "	embraced by 1 hoop of $\frac{3}{8}$" wire.
1712	"	155.25	152.94	2.31	1.49	4- " " " " " " " " " " " " " " " "	embraced by 11 hoops of $\frac{3}{8}$" wire.
1713	"	155.25	152.94	2.31	1.49	4- " " " " " " " " " " " " 90° " " "	
1716	"	155.88	153.57	2.31	1.48	4-Kahn bars .76" x .76 stems, with prongs bent inward at angle of 90° to axis.	
1715	"	155.50	153.69	1.81	1.16	4-Truscon bars, .76" diameter each. embraced by 11 hoops of $\frac{3}{8}$" wire.	
1705	"	113.47	113.47	None		None	
1706	"	113.47	113.47	"		"	
1707	"	113.10	113.10	"		"	

Concerning the amount of lateral expansion which accompanies the direct compression of the material, observations have been made on several columns. Measurements have also been made upon the expansion of the hoops of hooped columns during testing. Adjacent hoops have been found working under very different strains. The location of final rupture in unreinforced columns is often indicated prior to reaching the maximum load, by reason of the greater lateral expansion in that vicinity.

Columns have been made for test by long continued loads, and are now sustaining stresses of different amounts. The loads are maintained by means of groups of steel bolts which tighten end plates, between which the columns are located.

In conclusion, it is believed that the present tests are sufficiently advanced to clearly indicate that high ultimate strength may be reached by each of the three current methods of practice; that is, by the use of rich mortars or concretes, by means of sufficient longitudinal metal reinforcement, and by means of adequate hooping or other external lateral support. Rigidity of the columns will be attained by the use of rich cement mixtures or by means of longitudinal steel bars. The rigidity of the mortar or concrete itself is effected practically only by the use of rich cement mixtures. Economy of cost, to attain compressive strength, within certain limits, will be promoted generally by the plentiful use of cement.

DISCUSSION.

Mr. Talbot.

MR. A. N. TALBOT.—At the University of Illinois this last year tests were made on columns 12 inches square and 12 feet long, on others 9 inches square and 12 feet long, and on a few others of a length of six feet. A portion of these of each length and size were plain concrete columns; another portion had longitudinal rods at the corners extending through the length of the column; and still another had in addition to these longitudinal rods hoops or rods passing around the reinforcement at distances apart of about nine inches. All of the concrete was of the general mixture of 1–2–4. The reinforced columns gave a total ultimate load a trifle more on an average than the plain columns. But when the differences in the effective area, by counting the stiffness of the steel and adding the area of the steel times the ratio of the moduli of elasticity or of the relative proportions of stress to deformation is taken into account, the resultant unit stress for the plain concrete columns was more than that for the reinforced columns. The deformations were measured in a gauge length of about ten feet. There was every indication that the steel buckled before the ultimate strength of the column was reached. It was ordinary mild steel. This goes to confirm what has been said elsewhere, that the ordinary reinforcement by longitudinal mild steel rods does not give any particular additional strength to the column when central stresses are applied. This conclusion does not, of course, affect the problem of spiral hooping or other form of reinforcement, nor does it have any bearing upon whether the presence of such reinforcement will be an advantage if tension may be brought upon the column due to eccentric loading or settlement of the building.

Mr. Cummings.

MR. R. A. CUMMINGS.—I would like to ask Mr. Howard about the bearing of the platforms of his testing machine upon the ends of the columns, what influence that had on the results.

Mr. Howard.

MR. J. E. HOWARD.—The bars all came to full bearings. They were flush with the ends of the columns and rested directly against the platforms of the testing machine.

In regard to the effect of longitudinal reinforcement, it may be added, that the bars used had an elastic limit in excess of 60,000 pounds per square inch, not less than this is believed necessary in such bars. **Mr. Howard.**

These columns were unhooped, the concrete being relied upon to keep the longitudinal bars in position against lateral deflection. At the time of failure no doubt some buckling occurred. However, the lateral force necessary to retain the rods in position is not at times very great, and it was noticed, after failure, that buckling had been restricted to a short distance, the strength of the concrete being sufficient to retain the longitudinal bars in place through the remaining parts of their lengths.

The stresses on the bars, represented by the resilience, made it appear that they were stressed in the vicinity of 60,000 pounds per square inch, that is to say, several hundred thousand pounds compression were not infrequently sustained by the longitudinal reinforcement.

MR. G. LANZA.—I understood Professor Talbot to say that he estimated the amount of the load on the concrete to the load on the steel in his columns on the basis of the ratio of the two moduli of elasticity. I wish to ask whether he estimated the modulus of elasticity of the concrete as a constant, or whether he used for each separate load a different modulus of elasticity. **Mr. Lanza.**

MR. TALBOT.—I think I should not have used the term modulus of elasticity; I did not intend to use it. I did intend to use the ratio of the deformations which would come with the different loads, whatever this ratio may be called, and got at that for the reinforced columns from the amount of compression found on the columns with the given loads. **Mr. Talbot.**

MR. S. A. BROWN.—I should like to ask what probable difference there would be between a column tested horizontally and one tested vertically. I noticed in some of the pictures that the flaking seemed to be on the upper side, and I was wondering what effect that would have. **Mr. Brown.**

MR. HOWARD.—The difference amounts to about 50 pounds per square inch between the opposite sides of the column. Counterweighting would, of course, correct this, but from the manner of failure of the columns it is not thought that this difference in stress has materially influenced the results. Flaking occurs on all sides and does not begin on any particular one. **Mr. Howard.**

THE CONSISTENCY OF CONCRETE.

By Sanford E. Thompson.

The object of the experiments described in this paper was to determine the effect of employing different percentages of water with the same proportions of cement and aggregate. Incidentally, a few points of interest of a more general nature were noted.

Many engineers can recall the days when concrete specifications invariably included the requirement that the consistency should be such that "a film of water shall rise to the surface upon hard ramming," while nowadays we have passed to the other extreme, and we frequently see the advocacy of very wet, sloppy concrete, which in some cases results merely in a mixture of stones and watery grout.

A number of series of tests have been made in the United States with concrete of different consistencies, but the conclusions therefrom have been more or less contradictory. Recent European tests essentially confirm the results of the present series.

Conclusions.

The following principal conclusions are drawn from the experiments:

1. While a concrete of dry "damp earth" consistency is impracticable and not essential to the maximum ultimate strength, on the other hand, there is danger from a too large excess of water. Consequently, in building construction or other reinforced concrete work, concrete should contain only sufficient water to produce a consistency soft enough to flow sluggishly around and thoroughly imbed the steel and permit smooth surfaces against the forms.

2. A comparison of dry with medium "quaking" consistency indicates that while dry concrete thoroughly rammed in thin layers attains its ultimate strength at an earlier period, the medium mixture will closely approach and probably equal the dry after several months' hardening. If not thoroughly compacted, the concrete of dry consistency will have less strength than the medium.

3. An increase in the percentage of water beyond that necessary for a medium quaking consistency slightly decreases the density with a corresponding loss in strength.

4. A large excess of water, especially when the concrete is laid in water-tight molds, further reduces the strength and water-tightness of the concrete because of the formation of "laitance" and injury to the chemical setting of the cement.

Further incidental conclusions from the experiments are noted in connection with the description of details which follows.

DESCRIPTION OF EXPERIMENTS.

For determining the relation of consistency to strength, three consistencies were adopted, and there were made of each consistency six 12-inch cubes, four 8-inch cubes, and four beams, 8 inches square by 8 feet long. These tests were followed by a series of permeability tests employing five consistencies. The effect upon the density and tensile strength of mortars of varying the percentage of water was also studied incidentally.

The materials for all of the tests were Atlas Portland cement, Newburyport sand having a specific gravity of 2.65, and broken trap stone with specific gravity of 2.78.

The mechanical analyses were as follows:

MECHANICAL ANALYSES OF SAND AND BROKEN STONE.

Sand.			Broken Stone.		
Size of Sieves.		Total per cent. passing sieves.	Size of Sieves.		Total per cent. passing sieves.
Number.	Diameter of opening. Inches.		Number.	Diameter of opening. Inches.	
5	0.160	100.0	1 inch	1.000	100.0
12	0.0583	93.7	¾ "	0.748	73.0
40	0.0148	4.4	½ "	0.504	51.8
100	0.0055	0.2	¼ "	0.248	5.0
			No. 5	0.160	3.6
			" 12	0.058	0.6

The proportions in all the concrete specimens were 1 : 2.3 : 4.6, based on a unit of 100 pounds of cement to a cubic foot, but to insure greater accuracy, the materials were actually proportioned by weight upon the basis of sand (with natural moisture), 86

pounds per cubic foot, and broken stone, 85 pounds per cubic foot, these weights being obtained by experiments upon the materials employed. By weight the proportions were thus almost exactly 1 : 2 : 4.

Consistency of Mixtures.—The three consistencies employed in the strength specimens may be termed dry, medium and very wet.

The *dry* consistency was designed to have the appearance before placing of damp earth, with only sufficient water to glisten on the surface under hard ramming. As is the case in practice when laying dry concrete, some of the concrete after ramming scarcely glistened, while other specimens showed a decided film of water, or in some cases of mortar. These variations were found not to seriously affect the results, although when the mix was extra dry it was more difficult to compact the smaller 8-inch specimens, and their strength was consequently lowered.

The *medium* consistency contained sufficient water to look wet when mixed, but not to flow in the mixing box. It was soft enough for the rammers to sink into it slightly and produce quaking.

The *very wet* consistency, which was about like thick soup, contained so much water that it settled to a level in the mixing box, and required scoop shovels for handling. It was slightly wetter in fact, than is generally customary in building construction.

Percentages of Water.—The quantity of water in each batch was determined by the appearance of the concrete when being mixed. The percentages expressed in different ways averaged as follows:

Consistency.	Based on weight of cement. Per cent.	Based on weight of cement plus sand. Per cent.	Based on weight of cement plus sand, plus stone. Per cent.
Dry	34·3	11·7	5·0
Medium	44·7	15·2	6·5
Very wet	67·0	22·8	9·8

Percentages of water do not definitely define consistency, since not only do different brands of cement require different quantities of water to produce the same consistency, but still greater variation is caused by the sand, a fine sand or one containing a large percentage of fine grains frequently requiring twice

as great a percentage of water as coarse sand. A fixed percentage of water, therefore, will not necessarily produce the same consistency with different aggregates.

Furthermore, the natural moisture in the sand adds another uncertain element, while if several layers of medium or wet concrete are laid consecutively, the water works up through the mass, and the upper layers require less water to produce the same consistency.

Mixing the Concrete.—The cement and sand were mixed twice dry, shoveled on to the stone, and the mass turned twice dry, then the water was added, and the concrete turned three times wet.

A part of the beams were molded on end, and a part on their sides. The concrete in the horizontal beams and in the 12-inch and 8-inch cubes was compacted by square iron rammers in layers 2 or 3 inches thick in order to obtain the maximum density. Since this ramming was more severe than is possible in practice, duplicate experiments were afterwards made upon blocks about $4\frac{1}{2}$ inches thick, in which all the material was placed before beginning to ram. The wet specimens were rammed and puddled; the vertical molds were also pounded with a hammer to further settle the material and drive out the air.

Storage.—The specimens of the principal strength series were made about the middle of March and placed in the open air at a temperature averaging about 40° Fahr. for one month. The remainder of the term the 8-inch cubes and the beams were stored in the Massachusetts Institute of Technology laboratory at a temperature of 70° Fahr., while the 12-inch cubes were stored in a room at the Watertown Arsenal in a room slightly heated. The rest of the specimens were stored in a fairly damp basement.

Since the variety of treatment did not prevent similar results from each series, it is evident that the relative strength of the wet and dry specimens was not seriously affected by the method of storage.

RESULTS OF TESTS OF STRENGTH.

The results of the tests of the three principal series of strength tests are tabulated in Tables I, II and III, and the growth in strength is shown in Figs. 1, 2 and 3.

TABLE I.—COMPRESSIVE STRENGTH OF CUBES AND PRISMS OF DIFFERENT CONSISTENCY.

Proportions 1 : 2.3 : 4.6 *by volume.*

Place Tested.	Dimensions.	Dry.				Medium.				Very Wet.			
		Approximate Age.	Mark.	Weight per Cubic Foot.	Breaking Strength.	Approximate Age.	Mark.	Weight per Cubic Foot.	Breaking Strength.	Approximate Age.	Mark.	Weight per Cubic Foot.	Breaking Strength.
				lb.	lb.			lb.	lb.			lb.	lb.
Watertown Arsenal	12 in. cubes	30 days	I_1	151.7	4880	30 days	F_2	150.4	3360	30 days	T_2	150.7	2110
		30 days	I_3	151.1	4370	30 days	C_1	148.5	3100	30 days	Y_1	147.8	1710
			Average	151.4	4625	.....	....	149.4	3230	.....	....	149.2	1910
		60 days	I_2	150.0	5430	60 days	C_2	149.5	3940	60 days	T_3	152.7	2770
		60 days	L_1	150.4	5590	60 days	F_1	153.4	4780	60 days	Y_2	147.5	2180
			Average	150.2	5510	.....	....	151.4	4360	.....	....	150.2	2475
		6 mos.	L_2	150.3	5170	6 mos.	F_3	151.0	5170	6 mos.	T_1	151.4	3350
		17 mos.	L_3	155.5	5510	17 mos.	C_3	147.2	4720	17 mos.	Y_3	147.0	2430
Massachusetts Institute of Technology .	8 in. cubes	30 days	H_1	149.0	4100	30 days	A_2	150.4	2630	30 days	S_3	149.3	1690
		30 days	H_2	144.2	3210	30 days	A_3	148.1	2440	30 days	S_4	146.9	1370
			Average	146.6	3655	.....	....	149.2	2535	.....	....	148.1	1530
		60 days	H_3	142.7	3420	60 days	A_1	149.8	3830	60 days	S_1	150.5	2220
		60 days	H_4	142.8	3310	60 days	A_4	150.2	3300	60 days	S_2	150.0	1950
			Average	142.8	3365	.....	....	150.0	3565	.....	....	150.2	2085
Watertown Arsenal	4½ in. x 8 in. x 8 in. prisms	5¼ mos.	.....	142.9	3340	5¼ mos.	....	143.8	2890	5½ mos.	....	137.6	1500

In every case it will be seen that the strength of the specimens of dry and of medium consistency is greatly in excess of the very wet. The medium is lower in strength at an early age than the thoroughly compacted dry concrete but closely approaches it with age.

In Fig. 1, which represents the 12-inch cubes, the curves are not in every case drawn exactly through the points, because when the weight of the different specimens is taken into account, certain of the results are evidently slightly abnormal. Thus the medium and wet blocks tested at the age of seventeen months weigh only 147 pounds per cubic foot, while the ordinary weight is 150 pounds, and it is thus unfair to infer a decrease in strength at

TABLE II.—COMPRESSIVE STRENGTH OF SPECIMENS OF DIFFERENT CONSISTENCY ABOUT 9½ INCH DIAMETER BY 4½ INCH HIGH.

Tested at Watertown Arsenal. Age 5¼ months. Proportions 1 : 2.3 : 4.6.

Dry, Rammed Lightly.		Dry.		Medium.		Wet.		Very Wet.	
Weight per Cubic Foot.	Breaking Strength.	Weight per Cubic Foot.	Breaking Strength.	Weight per Cubic Foot.	Breaking Strength.	Weight per Cubic Foot.	Breaking Strength.	Weight per Cubic Foot.	Breaking Strength.
lb.	lb. per sq. in.	lb.	lb. per sq. in.	lb.	lb. per sq. in.	lb.	lb. per sq. in.	lb.	lb. per sq. in.
133.8	2580	144.2	4298	149.6	5149	149.0	4814	148.8	3524

seventeen months. Similarly, the dry mixed block at the same age is abnormally heavy, 155 pounds per cubic foot, so the average curve fairly passes below it.

The 8-inch cubes of medium consistency shown in Table I appear to pass the dry consistency blocks at the age of sixty days, but this is evidently due to the low weight of the latter, 143 pounds per cubic foot. Consequently, in Fig. 2 a slight allowance is made when drawing the curves. The small specimens at the foot of Table I show a set of blocks made at a different time by different operators, but which are in substantial agreement with the other tests.

Table II gives the results of still another series of tests, confirmatory of the results in Table I. Two specimens of dry con-

TABLE III.—TESTS OF 8 INCH BY 8 INCH BY 8 FOOT BEAMS OF PLAIN CONCRETE OF DIFFERENT CONSISTENCY.

Proportions 1 : 2.3 : 4.6 *by volume.*

Time Set.	Dry.					Medium.					Very Wet.				
Approximate Age.	Mark.	Span.	Weight per Cubic Foot.	Breaking Live Load.	Modulus of Rupture.	Mark.	Span.	Weight per Cubic Foot.	Breaking Live Load.	Modulus of Rupture.	Mark.	Span.	Weight per Cubic Foot.	Breaking Live Load.	Modulus of Rupture.
		ft.	lb.	lb.	lb per sq. in.		ft.	lb.	lb.	lb. per sq. in.		ft.	lb.	lb.	lb. per sq. in.
30 days	K	6.5	153.8	2115	534	B	6.5	148.9	1118	295	M	6.5	146.6	1068	287
	O	6.5	150.7	1800	449	E	6.5	150.3	1118	299	O	6.5	145.3	693	205
	K_n	3.25	153.8±	4600	524	B_n	3.25	148.9±	2270	270	M_n	3.25	146.6±	1908	226
	K_s	3.25	153.8±	4600	526	B_s	3.25	148.9±	2900	344	M_s	3.25	146.6±	2118	252
	Average	....	153.0	....	508	Average	....	149.2	....	302	Average	....	146.2	....	242
60 days	J	6.5	152.9	2250	552	D	6.5	151.2	1600	402	N	6.5	146.2	1300	339
	P	6.5	148.7	2200	552	G	6.5	150.9	1775	441	U	6.5	152.8	1650	431
	J_n	3.25	152.9±	5000	585	D_n	3.25	151.2±	4700	524	N_n	3.25	146.2±	2800	322
	J_s	3.25	152.9±	4350	509	D_s	3.25	151.2±	2800	330	N_s	3.25	146.2±	2800	331
	P_n	3.25	148.7±	4800	559	E_n	3.5	150.3±	3600	448	O_n	3.5	145.3±	1600	212
	P_s	3.25	148.7±	5150	610	E_s	3.5	150.3±	2900	378	O_s	3.5	145.3±	3300	429
	O_n	3.5	150.7±	4100	515	G_n	3.25	150.9±	4850	557	U_n	3.25	152.8±	3550	434
	O_s	3.25	150.7±	4900	586	G_s	3.25	150.9±	4200	486	U_s	3.25	152.8±	3700	447
	Average	....	150.8	....	558	Average	....	150.9	....	446	Average	....	148.4	....	368

sistency were made at this time. The first was only lightly rammed and the effect is shown by the the light weight and low strength. An additional consistency termed "wet" was introduced, and the strength of this mixture is seen to be nearly equal to the medium, while the strength of the very wet is very much lower, as in the previous tests.

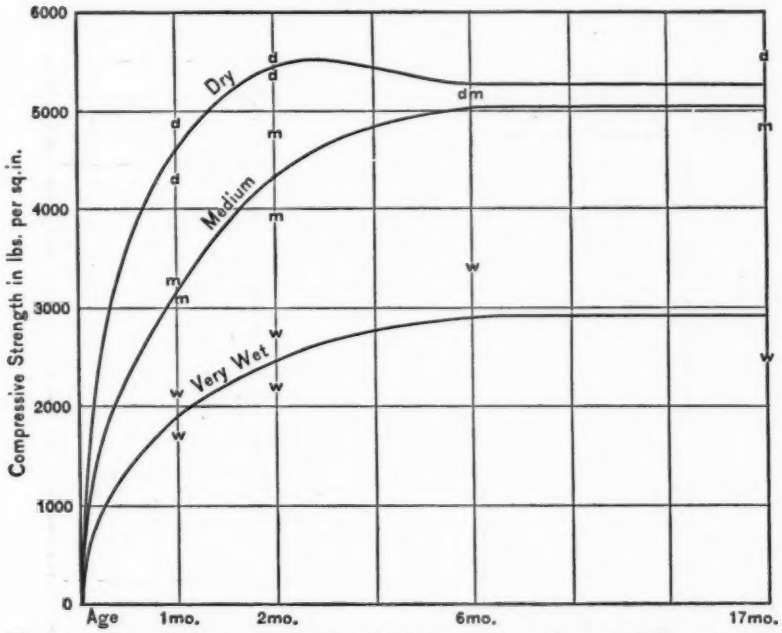


Fig. 1. Growth in strength of 12 inch concrete cubes of different consistency. Proportions 1:2.3:4.6.

The tests of the beams presented in Table III and Fig. 4 are more erratic than the compressive tests, but point to the same general conclusions.

The low weight and correspondingly low strength of certain of the 8-inch cubes of dry consistency in Table I, and the dry specimen in Table II, illustrate the difficulty of making perfect small sized specimens with a dry mixed concrete. Evidently, the stones arched and the specimens were not homogeneous. On the other hand, the 12-inch cubes and the 8-inch beams are as heavy when made with the dry mixture as with wetter consistency.

The uniformly lower strength of all the 8-inch cubes may be due to less perfect homogeneity or to the fact that they were crushed on edge instead of vertically as molded.

The specimens which reached a strength of 5,000 pounds, sheared through the stone when being crushed so as to form pyramids with nearly smooth surfaces. The specimens of lower strength tested at the same periods, produced similar pyramids

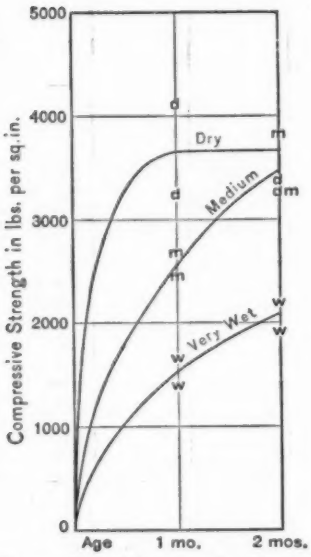


Fig. 2. Growth in strength of 8 inch concrete cubes of different consistency. Proportions 1:2.3 : 4.6

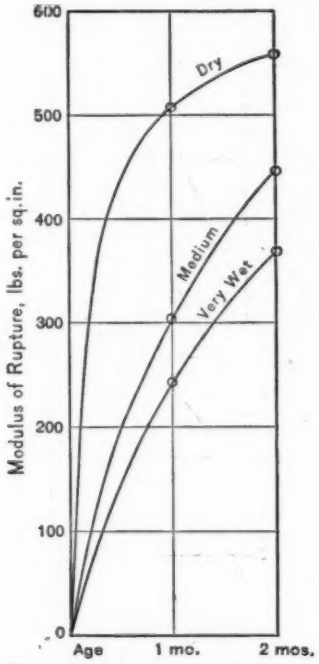


Fig.3. Modulus of rupture of 8 inch beams of different consistency.

when breaking, but the stones generally pulled out instead of shearing through.

Strength of Whole vs. Half Beams.—A comparison of the moduli of rupture of the whole beams and the half beams shows an average difference of only 2 per cent.

Relation of Compressive to Transverse Strength.—The average compressive strength per square inch of the 8-inch cubes was about seven times the unit transverse strength or modulus of

rupture of the 8-inch beams. The 12-inch cubes were nine times stronger in compression than the 8-inch beams under transverse load. The latter is the more correct comparison because the 12-inch cubes were nearly identical in weight with the 8-inch beams.

Injury due to Laitance Formation.—In the specimens prepared for the permeability series to be described, a laitance formation was noticed on the surface of the blocks after setting, varying from 0 inch thick for the mixture of dry consistency up to $\frac{1}{8}$ inch for the very wet. No laitance formed on the surface of the cubes or beams molded on edge, because the surplus mortar was removed, but in all the very wet specimens wherever a large void occurred, due to imperfect mixing or placing of the material, this same laitance was deposited in the form of a layer of light-colored matter having very slight cohesion. Moreover, throughout the interior of many of the very wet blocks, the color, instead of being a cement gray, was nearly white.

The laitance was of cheese-like consistency, turned white on exposure to the air, and never attained great hardness. Mr. Clifford Richardson kindly examined and analyzed a sample of it. His results and conclusions are here given:

The composition of the laitance is as follows:

	Per cent.
Silica (SiO_2)	16.00
Alumina and Iron ($Al_2O_3Fe_2O_3$)	8.66
Lime (CaO)	47.40
Magnesia Oxide (MgO)	2.40
Ignition loss	23.60

If this is calculated to a water and carbonic acid free basis, the analysis becomes:

	Per cent.
Silica (SiO_2)	20.94
Alumina and Iron ($Al_2O_3Fe_2O_3$)	11.30
Lime (CaO)	62.94
Magnesia Oxide (MgO)	3.14

It is evident from these figures that the laitance consists of all the elements originally contained in the Portland cement, in fact, its composition corresponds exactly with that of a normal Portland cement except that it is unusually high in alumina and iron. It is not a simple hydrate or carbonate of lime.

I have had a thin section ground, but find that it shows no structure which is characteristic. The section consists largely of amorphous material of an isotropic nature, that is to say, it does not affect polarized light. It reveals a considerable amount of a yellow substance which seems to be the undecomposed magma contained in the orginal cement. The presence of this magma may explain the unusual percentages of alumina and iron. I have made a material very similar to the laitance by shaking Portland cement with water, decanting the finer portion, and allowing it to settle out, and harden. This material, like your laitance, is rather soft and this is due to the fact that the Portland cement is much more thoroughly decomposed under these conditions than under ordinary ones, which accounts for its character.

Where an excess of water is present in a mortar, this excess, through the subsidence of the cement particles by gravity, is brought to the surface, carrying with it the finer particles of the cement. These particles, being so fine, are entirely, or much more thoroughly, decomposed than the remainder of the cement, with the formation of the very light colored laitance. The composition of this should not be, and is not found to be different from that of the original cement.

Mr. Richardson states that by elutriating cement he has obtained so fine particles that they are quite decomposed and hydrated on setting, and then become white in color and attain very little strength. This has the appearance of the laitance on the blocks except that it is whiter, resembling a hard, cream-white chalk.

The strength, and, as will be discussed later, the water-tightness, are thus decreased when laitance is formed, by the extraction from the concrete or mortar of a portion of the cement, a portion which from Mr. Richardson's researches appears to be the finest, and therefore the most adhesive grains. The cement thus withdrawn will not crystallize or harden and so is wasted.

Formation of Laitance in Leaner Specimens.—A few specimens were mixed in proportions 1 : 2.3 : 5.8, instead of 1 : 2.3 : 4.6, to determine the effect of increasing the proportion of stone. The cubes did not differ greatly in strength from the richer cubes in Table I. However, the very wet beam molded on end showed an extremely low strength, breaking with its own weight at thirty days, and the half beams attaining a modulus of rupture of only 105 to 143 pounds per square inch at the age of sixty days. The probable explanation of this low strength is indicated by the

appearance of the specimen after breaking, the two faces of the break being shown in Fig. 4.

At the right is the fractured surface of the lower portion of the beam after breaking, and at the left the adjoining surface of the upper half of the beam. Upon the lower surface, as shown more or less clearly in the photograph, the powdered laitance settled, covering the stones, while the stones of the upper surface are sharp and clean.

Effect of Tight vs. Porous Molds.—The forms in which the specimens were molded were made practically water-tight, any

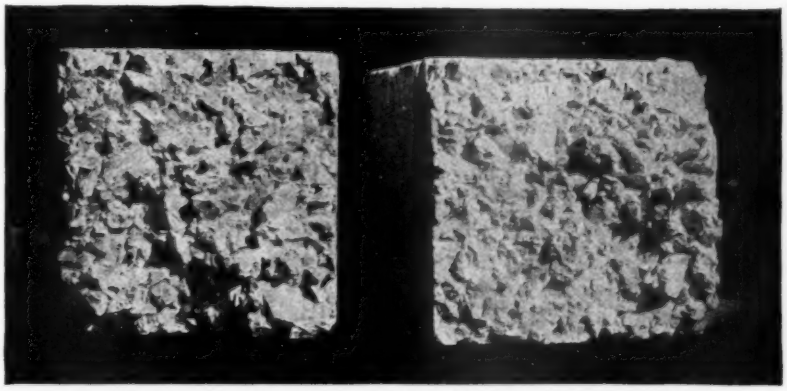


FIG. 4.—Photograph showing adjoining Broken Surfaces of Beams of Leaner Concrete.

slight leakage being closed immediately by the cement. The question naturally arises as to the effect upon the very wet specimens of thus retaining the excess water in suspension. To decide this point, a series of tests was made, using tight molds and also molds loosely tacked together with cracks between the boards to allow the excess water to escape.

The result of these tests is shown in Table IV. The lower strength of the concrete when formed in the tight molds is evident. The specimens which were rammed or puddled violently were noticeably smaller in volume than those rammed lightly, and the density was therefore greater, as indicated by the higher weight per cubic foot.

The proportions and conditions of manufacture of these

blocks coincide with tests previously described, so that the results may be directly compared with them.

Inspection of the table shows the specimens in the tight molds to be very similar in strength to the 8-inch cubes at one month given in Table I. The porosity of the molds appears to increase the strength about 25 per cent. However, referring to Tables I and II, we find by averaging the eight sets of comparative tests that the average strength of the medium consistency is 71 per cent. higher than that of the very wet. It is thus fair

TABLE IV.

EFFECT OF TIGHT VS. POROUS MOLDS UPON CONCRETE OF VERY WET CONSISTENCY.

Tests of 8-inch Cubes; Proportions 1 : 2.3 : 4.6 by volume, or 1 : 2 : 4 by Weight. Age one month.

Mark.	Mold.	Ramming.	Weight per cu. ft.	Compressive Strength.	
				Individual lb. per sq. in.	Average lb. per sq. in.
(1)	tight.	light.	149.9	1470	1425
(5)	"	"	148.2	1380	
(2)	"	violent.	151.6	1410	1410
Average for tight mold.....			149.9	.....	1418
(3)	Porous.	light.	150.9	1790	1700
(7)	"	"	149.7	1610	
(4)	"	violent.	151.8	1830	1860
(8)	"	"	153.7	1890	
Average for porous mold ...			151.5	.....	1780

to conclude that only a small part of this difference is due to the tightness of the molds.

That even a loss of cement with the water which escapes, may not lessen the strength (provided of course the quantity lost is not sufficient to make stone pockets in the concrete) is indicated from the fact that the specimen of highest strength lost an appreciable quantity of cement through the cracks in the mold—sustaining in fact a greater loss than all the other specimens combined.

MODULUS OF ELASTICITY.

Determinations of elastic deformation were made at the Watertown Arsenal, upon twelve of the 12-inch cubes, using a

5-inch gauged length. Although the deformation of cubes may not exactly correspond to prisms or columns, the results may be considered of comparative value.

The elastic deformation, that is, the gross deformation minus the permanent set due to the removal of the load at intervals of 500 pounds per square inch, forms a curve which is practically a straight line for the specimens of dry and medium consistency up to a load of at least one-half the ultimate strength. The specimens of wet consistency, except at the one month period, also showed a deformation curve only slightly curved up to nearly one-half the ultimate load, but their permanent set was very much greater and the modulus very rapidly dropped after passing the point of maximum curvature.

The moduli, figured for portions of the curves which were nearly straight lines, are given in Table V.

The comparatively low modulus of very wet concrete is of interest in reinforced concrete design.

Another point of interest in the elasticity results is the fact that in these tests with similar concrete there is no appreciable increase in the modulus with age.

TESTS OF PERMEABILITY.

The series of permeability tests was made to determine the relative effect of the consistency of the concrete upon its water-tightness, the same proportions and materials being employed as in the strength series already described. The most water-tight mixtures were found to be those of medium and of wet consistency. Very wet mixtures allowed more water to pass, and mixtures of dry consistency passed more than the very wet.

The number of experiments in the permeability series was so small that the results might not be worth presenting were it not for the meagerness of the data upon this very important subject of water-tightness, and the difficulty in preparing specimens for satisfactory tests.

The mixtures were of five consistencies, and the results of the tests are shown in Table VI. The first specimen marked "Dry, slightly rammed" was mixed with only sufficient water to give it the appearance of damp earth, placed in the mold and com-

TABLE V.—MODULUS OF ELASTICITY OF CONCRETE OF DIFFERENT CONSISTENCY.

Proportions by volume 1 : 2.3 : 4.6, *or, by weight* 1 : 2 : 4.

Dry.				Medium.				Very Wet.				
Approximate Age. Months.	Mark.	Compressive Strength. Lb. per sq. in.	Modulus taken between loads. Lb. per sq. in.	Modulus of Elasticity. Lb. per sq. in.	Approximate Age. Months.	Mark.	Compressive Strength. Lb. per sq. in.	Modulus taken between loads. Lb. per sq. in.	Modulus of Elasticity. Lb. per sq. in.	Approximate Age. Months.	Mark.	Compressive Strength. Lb. per sq. in.	Modulus taken between loads. Lb. per sq. in.	Modulus of Elasticity. Lbs. per sq. in.
1	I_3	4370	500—1500	4,000,000	1	F_2	3360	500—1500	4,400,000	1	T_3	2110	500—1000	2,200,000
2	I_2	5430	500—1500	4,300,000	2	C_2	3940	500—1500	4,700,000	2	T_2	2770	500—1500	3,800,000
6	L_2	5170	900—1500	5,000,000	6	F_3	5170	600—1500	3,800,000	6	T_1	3350	500—1500	3,400,000
17	L_3	5510	500—1500	4,500,000	17	C_3	4720	500—1500	3,900,000	17	Y_3*	2430	500—1200	2,600,000

*The low strength of this specimen is accounted for by its low weight per cubic foot.

pacted so lightly that the appearance was rough and very porous. The next specimen, mixed to a similar dry consistency with the same percentage of water, was placed in the mold to the full depth of 4½ inches and rammed so as to bring moisture to the surface. The remaining specimens, containing increasing percentages of water, were rammed just enough to drive out the air and produce a compact and homogeneous mass. The relative water-tightness of the different specimens was determined by the quantity of water flowing per minute through the specimen under pressure of eighty pounds per square inch, the maximum flow being recorded.

Method of Testing Permeability.—The test was made by cementing a short piece of 1-inch pipe to the top of the block after roughening and wetting it, by means of a cone of neat cement, then connecting this pipe with the city water pressure. This plan gave fair satisfaction, but required careful workmanship to prevent leakage around the pipe under the high pressure which gave the best relative results. The compressive strength of the same specimens was determined by clipping off the cone and capping with a thin layer of neat cement.

Frequent improvements in the method of forming the permeability specimens for subsequent tests have finally resulted in a modification which gives excellent satisfaction, except that it is impossible to determine the exact weight or density of the concrete. However, a separate specimen may readily be made for this determination.

Instead of first making the concrete block and then connecting the nipple with it, the specimen and its cement coating are formed at one operation. Since ramming brings the cement to the surface, the specimen must be molded upside down. The method of forming it is shown in Fig. 5, and the specimen ready to test in Fig. 6. Having selected the size and shape of the specimen,—which may be either round or square,—and prepared the mold, a piece of wrought iron pipe about 4 inches long, with an increasing bushing made up on to the end of it, is placed upright in the bottom of the mold, and a crater of very fine, wet sand formed around it. Neat cement of plastic consistency is then placed around the pipe to within ¼ inch of the top of the nipple, and is also plastered around the sides of the mold. Before

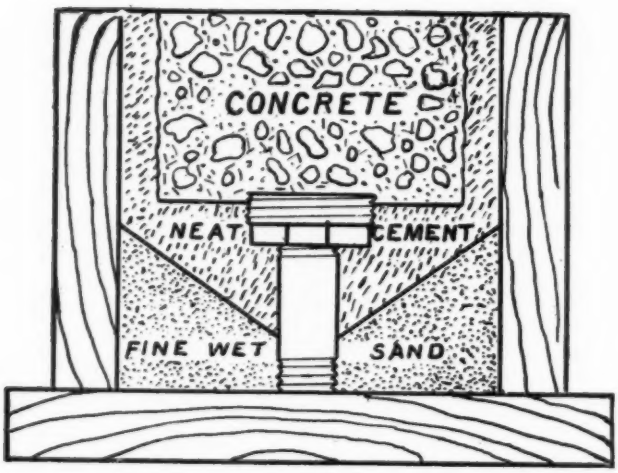


FIG. 5.—Permeability Specimen as Molded.

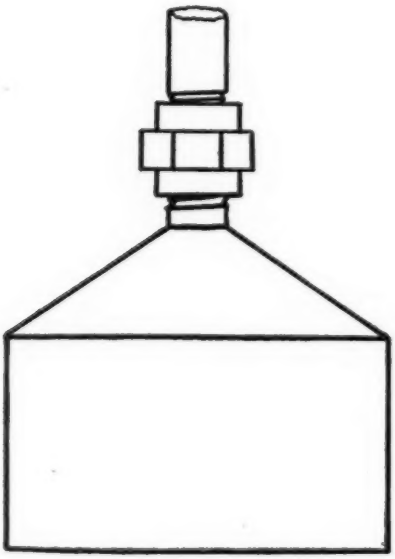


FIG. 6.—Permeability Specimen as Tested.

this has commenced to set, the concrete is placed within it. To better hold the neat cement in place, a thin metal mold of smaller size with no bottom may be set within the other, to be withdrawn as the concrete is placed.

By permitting the specimen to set in the mold for about a week in a sheltered place, the cement is prevented from checking, and after soaking in water for twenty-four hours, the specimen is ready to connect with the pressure, as shown in Fig. 6. The water passing through, is caught in a pan, and weighed at frequent intervals to determine the rate of maximum flow.

Effect of Surface upon Permeability.—The specimens shown in Table VI were made before the effect of the surface of the specimen was considered, and the pressure was directed against the surface of the block as molded. Subsequent tests showed that inverted specimens permitted a much greater flow of water, but a few comparative tests, duplicating the original set, indicate that the relative permeability of the blocks of different consistency was not greatly different by the two methods.

The important effect of the surface on water-tightness is shown by the following test of specimens alike in all other particulars:

Flow against top of specimen as molded, 0.3 gram per minute.

Flow against bottom of specimen as molded, 170.1 grams per minute.

Other tests gave a similarly high ratio.

Undoubtedly the troweling of the surface of concrete, which has been found so effective in practice for increasing the water-tightness of dams and other structures, is a still more effective application of the same principle.

Effect of Addition of Slaked Lime upon the Water-Tightness.—A few specimens were made with a small addition of slaked lime putty, with the results shown in Table VII. Every specimen with lime showed a marked increase in water-tightness over a similar specimen made without lime. In subsequent experiments, not here recorded, hydrated lime was substituted for lime putty.

Effect of Age upon the Permeability.—A few specimens were tested at two different ages. The rate of flow on the average was found to decrease about 50 per cent. between the ages of twenty-one and eighty-four days.

TABLE VI.—PERMEABILITY TESTS OF CONCRETE BLOCKS OF DIFFERENT CONSISTENCY.

Proportions 1 : 2.3 : 4.6 *by volume. By weight,* 4 *lb. cement,* 8 *lb. dry sand,* 16 *lb. stone. Age* 21 *days.*

Mark.	Consistency.	Per cent. water by wt. of cement and sand.	Per cent. water by wt. of cement, sand and stone.	Elementary volumes of materials in set mortar.*					Density.	Total volume of specimens.		Thickness of Laitance.	Weight per cubic foot, set.	Permeability. Water passing in grams per min.	Compressive strength at 84 days.	Remarks upon Crushing.
				Cement.	Sand.	Stone.	Water.	Air voids.		Green.	Set.					
		Per cent.	Per cent.	c	s	g	w		c+s+g	cu. in.	cu. in.	in.	lb.		lb. per sq. in.	
(1)	Dry light-rammed.	12.5	5.4	.094	.221	.425	.095	.165	.740	377	377	none	133.8	686.0	2580	Porous. Stones not broken.
(2)	Dry	12.5	5.4	.101	.236	.457	.109	.097	.794	350	350	none	144.2	125.8	4298	Some pores. Stones slightly broken.
(3)	Medium ..	16.2	6.9	.104	.243	.466	.140	.047	.813	344	343	0.02	149.6	1.6	5149	Dense. Stones broken.
(4)	Wet	21.6	9.2	.101	.237	.459	.175	.028	.797	350	348	0.02	149.0	0.1	4814	Some stones broken.
(5)	Very wet ..	25.7	11.0	.100	.234	.454	.198	.015	.787	369	352	0.12	148.8	17.0	3524	Stones slightly broken.
(6)	Extremely wet.	32.0	13.7	.099	.233	.452	.216	.000	.784	378	354	0.06	149.8	85.3	....	Specimen broken.

*Not allowing for chemical changes.

TABLE VII.—EFFECT OF ADDITION OF SLAKED LIME UPON PERMEABILITY.

Proportions 1 : 2.3 : 4.6 *by volume. Age* 21 *days.*

Mark.	Consistency.	Per cent. water by wt. of cement, lime and sand.	Per cent. water by wt. of cement, lime, sand and stone.	Weight of materials.					Total volume of specimens.		Weight per cubic foot, set.	Permeability. Water passing in grams per min.	Compressive Strength at 84 days.	Remarks.
				Water.	Cement.	Lime.	Dry sand.	Stone.	Green.	Set.				
		Per cent.	Per cent.	lb.	lb.	lb.	lb.	lb.	cu. in.	cu. in.	lb.		lb. per sq. in.	
(1)	Medium.....	16.2	6.9	1.04	4	0	8	16	344	343	149.6	1.7	4510	Pressure against top surface of block, as molded.
(2)	"	16.2	6.9	1.04	3.6	0.4*	8	16	....	341	150.5	0.2	3550	
(3)	Extremely wet..	32.0	13.7	3.84	4	0	8	16	385	360	146.4	1384.	....	Pressure against bottom surface of block, as molded.
(4)	" ..	32.0	13.7	3.84	3.6	0.4*	8	16	393	368	148.8	128.	....	

*Lime paste used here measured 8.1 cu. in. in volume. On drying at 212° Fahr. weight is reduced by 57.7% moisture.

RELATION OF DENSITY TO PERMEABILITY AND STRENGTH.

The volume of neat paste made from a given weight of cement varies, even after setting, with the percentage of gauging water. With 50 per cent. of water, for example, I have found the volume of set paste to be in some cases 1.3 times the volume when gauged with 25 per cent. of water, with a corresponding decrease in density. Also, on sand mortar the usual effect of gauging to a softer than plastic consistency is to considerably increase the bulk of the set mortar, a mortar of coarse sand being less affected than one of fine sand. With concrete an increased percentage of water has still less effect, but even so, the slightly reduced density appears to be responsible in part for the lower strength of the wet concrete.

The relation of the density* to the strength and permeability of concrete of several different consistencies is illustrated in Fig. 7, which is drawn from data in Tables II and VI.

As previously indicated, the strength of the "dry" specimen is slightly lower proportionally than in some of the other tests.

In the three curves the points of maximum density, strength and water-tightness all lie not far from the medium quaking consistency, although for maximum water-tightness a softer consistency appears to slightly increase the water-tightness.

THE CONSISTENCY OF MORTAR.

A few tensile tests were made with mortars of Atlas cement and Newburyport sand mixed to different consistencies, and the results at the ages of seven and twenty-eight days are shown in Fig. 8.

Only three or four briquettes were tested at each age with each per cent. of water, so that there are one or two erratic points, but the general form of the curves is definite, the strength decreasing with the larger percentages of water, but to a less degree in the twenty-eight day than in the seven day tests.

---

*The term *density* is used in its meaning now generally accepted, as the ratio of solid particles in a unit volume of concrete. It is thus the complement of the voids. For example, if a piece of concrete has 15% voids (including the air and the water), 85% of its volume must be solid material, and its density is 0.85.

The lower curves in the same diagram give the elementary volumes of the cement, and also the density, that is, the elementary volumes of the cement plus sand in the mortars. These mortars were made from the same batch as the briquettes of

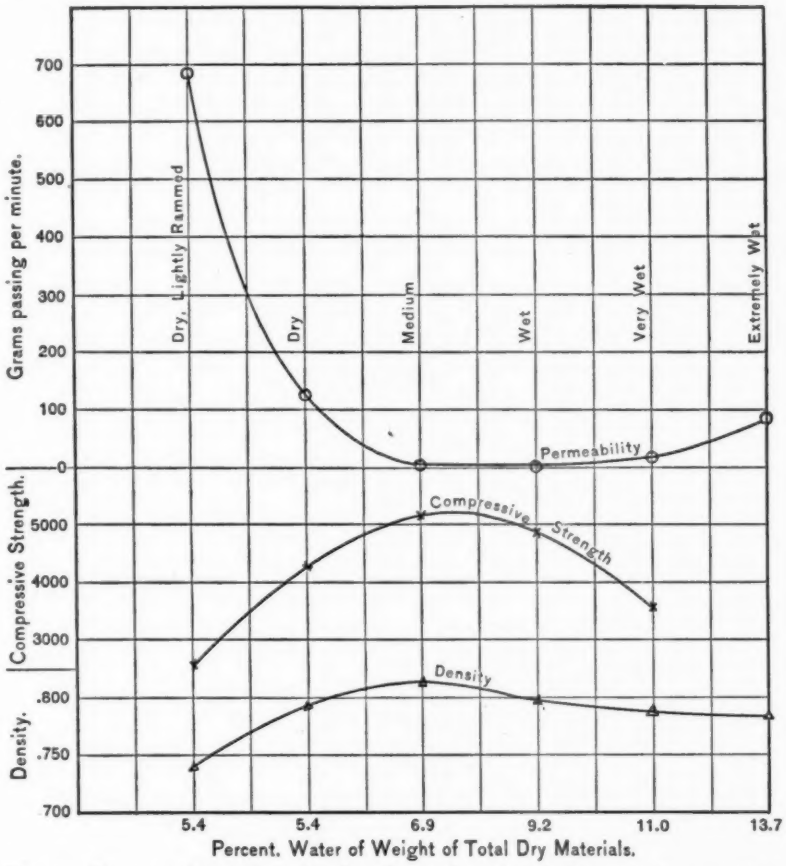


Fig. 7. Comparative strength, density and water-tightness of concrete of different consistency.

similar consistency and measured in a glass graduate. The point of maximum curvature in the density curves is to the left of the strength curve, but this may be due to the difference in ramming of the briquettes and the density specimens. The density of all the specimens grows less as the water is increased beyond

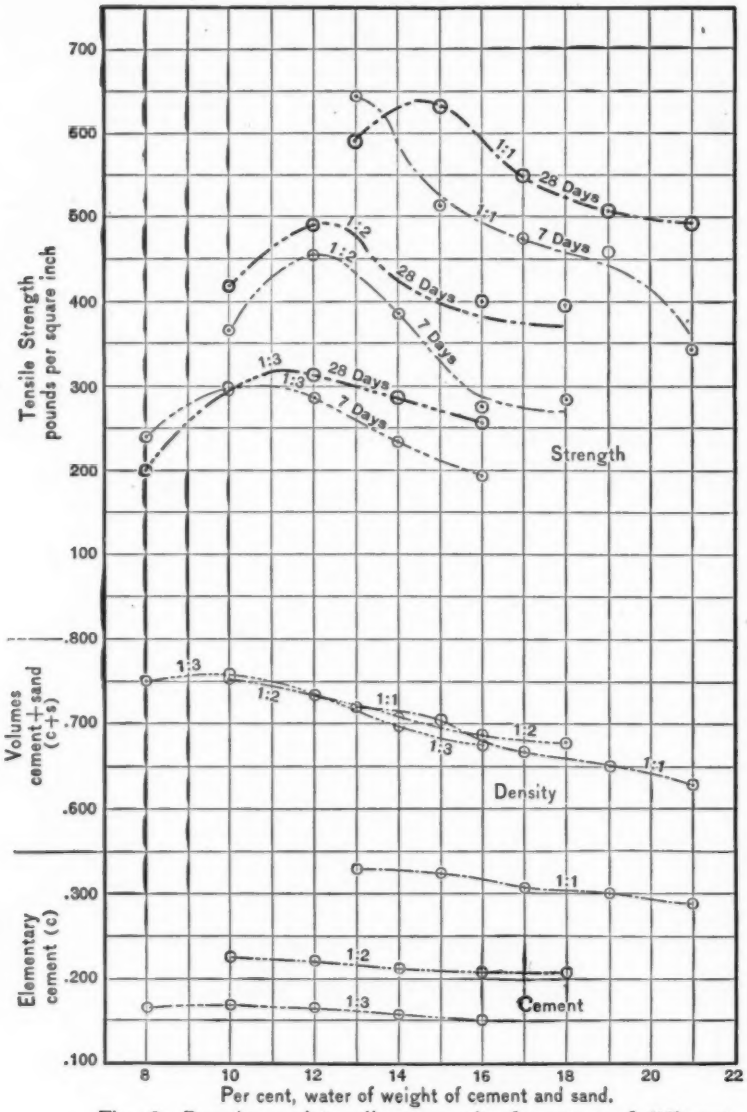


Fig. 8. Density and tensile strength of mortars of different consistency.

the percentage required for the maximum. Another fact of interest is the similarity in the density of the mortars of different proportions when mixed with like percentages of water.

EFFECT OF CONSISTENCY UPON ADHESION TO STEEL.

Although no tests of the effect of the consistency of concrete upon its adhesion to steel are included in this series, the relation is of such importance that we quote from the conclusions of Mr. R. Feret, from tests made by him in France,* which apply to the union of steel and concrete as well as adhesion to stone:

> Adhesion, which is zero or nearly zero for mortars mixed dry, rapidly increases as the proportion of water is increased, and reaches its maximum value for mortars of plastic or slightly soft consistency. Adhesion to stone, even when care be taken to wet them, is often highest for plastic mortars, but as the proportion of water is increased, the adhesion decreases more or less slowly.
>
> The maximum strength in adhesion nearly always corresponds to a consistency a little wetter than that for maximum compressive strength, which in turn generally corresponds to a consistency a little less dry than that required for maximum density.
>
> The influence of the quantity of water for gauging concrete appears similar to that found with mortars.

PRACTICAL RULES FOR FIXING CONSISTENCY.

In many classes of concrete construction it is entirely impracticable to specify either a dry or a "medium quaking" consistency. In reinforced concrete, for example, of more importance than the strength is the proper imbedding of the steel so that the air voids shall not permit rusting or prevent adhesion. Tests of Professor Charles L. Norton for the Insurance Engineering Station at Boston† indicate the absolute necessity of a fairly wet consistency to attain this end. The perfect filling of the forms to insure smooth surfaces is also an essential in walls exposed to view. At this time, however, there seems to be need to emphasize the advisability of limiting the mixing water to the minimum quantity which will permit perfect coating of the steel

*Translated from Baumaterialenkunde, Jan. 1, 1906.

† See Taylor & Thompson's "Concrete, Plain and Reinforced," p. 427.

and filling of the forms. The practical necessity of this is evidenced not only by the lessened strength and water-tightness, but by the fact that a large excess of water, instead of improving the appearance of the surface of the concrete, tends to produce stone pockets resembling those in an excessively dry mix.

These experiments and practical experience suggest the adoption of the following rules for fixing the consistency of concrete for a given structure.

1. Dry concrete may be used, although at a higher cost, for mass foundations to be subjected to severe compressive loading within one or two months, provided the concrete is carefully spread in layers 4 to 6 inches thick, and rammed so as to bring water to the surface.

2. Medium or quaking concrete is suitable for ordinary mass concrete, such as foundations, heavy walls, large arches, piers and abutments.

3. Wet or mushy concrete is required for rubble concrete, and for reinforced concrete such as thin building walls, floors, columns, conduits and tanks, but the consistency should be as thick as will flow sluggishly and thoroughly coat the steel or large rubble stones.

APPRECIATION.

The author desires to acknowledge the cooperation and assistance of the following gentlemen in connection with the experiments above described: Mr. Frederick W. Taylor, with whom the tests were jointly made; Messrs. Charles L. Bates and Robert A. Cook, students at the Massachusetts Institute of Technology, Class of 1903, who assisted in making the experiments; and professors and instructors of the Institute to whom he is indebted for use of testing apparatus.

APPENDIX.

For the purpose of further investigation of the subject of consistency, the following references to literature are noted. The percentages of water in these concrete tests in the United States vary from 3.4 to 9.4 per cent. to weight of total dry materials, Mr. Rafter's ranging from about 5 per cent. in his "Dry"

block to 6½ per cent. in his "Excess" specimens. In the European tests the percentages are much higher, but smaller stone was used and a larger proportion of sand to stone, so that more water was required to produce the same consistency.

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DISCUSSION.

Mr. Taylor. MR. W. P. TAYLOR.—I should like to comment on what is to me the very false impression given by the diagram showing the variation in strength with the consistency of the concrete. Whenever a practical engineer is discussing wet and dry concrete, it will be found that he will almost invariably prefer the wet mixtures, while a man whose experience has been confined to the laboratory will consider the dry concretes superior. Both men are correct, but judge from a different standpoint, the difference being in the amount of manipulation and compacting given the material. Dry concretes almost invariably give the better results in laboratory tests, but it may readily be computed that, if the same time was employed in the field on tamping and placing as is used in the laboratory in making a six-inch cube, it would take four men a day's work to compact a yard of concrete. In the field, where it is impracticable to work the material for anything like that time, it will be found that the wetter mixtures, which compact easier and with much less labor, will usually produce the better results. This condition should always be borne in mind when the results of tests of wet and dry concrete are considered.

Mr. Talbot. MR. A. N. TALBOT.—Mr. Thompson has an item on the storage of these cubes. I should like to call attention here to the difference in the crushing strength of concrete cubes, due to the way in which they are stored. The method of storage will greatly affect the results, according as the material is kept dry or moist or very wet. If the material is dry and is left in a room where there is much chance for evaporation, the results will be far lower than will be found if the pieces are stored, say, in damp sand, or kept in a very damp place. Foundations, of course, will generally be damp enough for the purpose of securing good setting; but in much of our building construction it seems to me that greater care should be taken to keep the materials at least free from becoming very dry, or very poor concrete will be the result. This matter of drying out during the time of setting is important, not only in investigational work, but also in building construction and builders should give more care to avoid improper conditions for the setting of the concrete.

MR. JOHN G. BROWN.—The U. S. Army engineers made a very elaborate set of tests in connection with the permeability of mortars which had never been published. They were made by Lieutenant Spencer Cosby's corps, at a time when there was a great deal of discussion about the water-tightness of the Queen Lane Reservoir; and at the same time the United States Army were having difficulty all over the country in trying to keep their magazines dry. There was a thought that by using a rich mixture of concrete they would overcome the tendency of the water to percolate through the batteries. Six months were devoted to these tests by one man and two assistants, who made many specimens of different mixtures of concrete, which were tested at different periods. The specimens were made of 1:2 mortar; then of 1:2 mortar backed up with 1:2:4 concrete; then other proportions were tried up to 1 part of cement to 4 of sand and 10 of stone. It was found in connection with the 1:4:10 concrete that at the end of the first week, clear water ran through there very rapidly. After the specimen had hardened three weeks the water did not go through as quickly, and at the end of three months when the specimen was subjected to hydrostatic pressure of 250 pounds per square inch, no water came through. These blocks were made up of 2 inches of mortar and 4 inches of concrete. **Mr. Brown.**

MR. SANFORD E. THOMPSON.—When we capped the concrete in the tests referred to, we did find occasionally a slight leakage. However, when leakage occurred it was always observable, so that we could tell a poor specimen and repair it. The later method illustrated in Figs. 5 and 6 entirely prevents the leakage, because the concrete and the neat cement coating are laid at the same time. If a specimen of set concrete is to be coated with neat cement the skin must be entirely chipped off with a cold chisel, the concrete surface soaked with water and the cement for the coating mixed to a rather stiff plastic consistency. **Mr. Thompson.**

S. A. BROWN.—How did you determine the percolation of water? **Mr. Brown.**

SANFORD E. THOMPSON.—By gaging the water which passed through. The pressure is turned on and the time is noted at which the water first flows through; then the water which passes through is weighed at definite intervals, of say, 5 minutes. A number of determinations, are made and the maximum rate during **Mr. Thompson.**

Mr. Thompson. a period of fifteen minutes is taken as the flow. I will say, in reference to Mr. Brown's point about the hollow, that we always follow the practice of gouging out the concrete in the interior of the nipple so as to have a fresh surface of concrete at the point of pressure.

Mr. Humphrey. MR. RICHARD L. HUMPHREY.—A method used in the St. Louis laboratory for determining the permeability or rate of flow of water under pressure through a mass of mortar or concrete consists of a cylinder 8 inches in diameter, 16 inches long, in which is embedded an inch pipe. The mortar or concrete is molded into a cylinder, in the center of which is a two-inch pipe running to within six inches from the bottom. After the concrete or mortar has partially hardened this pipe is removed and an inch pipe inserted at the end of which is fitted a washer two inches in diameter. This pipe is lowered so that the washer at the end of the pipe is six inches below the top of the cylinder and the space around the inch pipe is filled with neat cement. The inch pipe has on the outer end a part of a union which connects with the tank arranged for measuring the amount and pressure of the water flowing into the cylinder. The amount of leakage around the joint of this apparatus seems to be very small and the apparatus in other respects seems to be satisfactory.

Mr. Birkinbine. MR. JOHN BIRKINBINE.—I agree with Mr. Taylor that the results obtained in the laboratory and in practice often differ widely; but I do not agree with him that all engineers prefer wet concrete. The discussion has been mainly on results obtained in test specimens; but when concrete is used in construction we want impermeability so that our reservoirs or other structures shall not leak. I question the desirability of very dry concrete, but I am more opposed to very wet concrete. I realize that it is essential, in making a cement, that there should be enough water to form the necessary combination, and that anything beyond what is required is a detriment. We were taught in school that two substances cannot occupy the same space at the same time; and if we have an excess of water, this must find its way out somewhere or leave voids in the construction. Therefore, I think very wet concrete is objectionable in large structures.

NOTES ON COMPRESSION TESTS OF CEMENT.

By W. Purves Taylor.

Although compression tests of cement mortars are given an important place in most text-books and in academic research, their use in every day routine is extremely infrequent and investigation will show a surprisingly limited amount of data that can be considered reliable and authentic. The argument often advanced —that since cement and concrete are used mostly in compression the tests should also be so made—is not without fallacy, but at the same time has more truth in it than most testers of cements are willing to assign it. The practical reasons that count most against the use of this test are three—the greater amount of material necessary for making the common specimen, the 3-inch cube, the greater strength and hence larger testing machine required for breaking the specimens—and the use of a specimen more likely to be injured in making, storing and testing.

In commencing last fall to make a series of compression tests in the Philadelphia laboratories, the first point was to devise a suitable form of test-specimen, it being obvious to any one conducting a commercial laboratory that for the reasons just given, the ordinary 2-inch cube is utterly impracticable in ordinary routine. One-inch cubes are better in point of size, but to make them uniformly and without imperfections is a most difficult and tedious operation. As a result of the trial of several forms, it was found that the best form of specimen, if indeed not the only form, adapted in all respects to meet the requirements of commercial work was that of a cylinder one inch in height and having a diameter of a little over an inch and an eighth, giving an area of one square inch. The specimens are made most conveniently when the molds are in gang form, an 8-gang cylinder mold being about the same general size as the common 3-gang briquette mold. Moreover, the standard methods as proposed by the Committee of the American Society of Civil Engineers for molding tensile briquettes can be followed exactly when these cylinder

gang molds are used, a condition practically impossible with any other form of specimen.

From a practical standpoint the manipulation of these cylinders is even more simple than in the case of tensile briquettes —there is less material to handle—less danger of damage on removing from the molds—and less space required in storage, while on account of their shape they may be compacted under hand methods with even greater uniformity. The common acceptance tests of 1:3 mortars at seven and twenty-eight days may be readily broken on one of the common cement machines of the long lever type. Neat specimens and long time mortar specimens have however the disadvantage of requiring a larger machine of 12,000 or 15,000 lbs. capacity. The specimens are best broken when bearing directly on the steel surfaces without the interposition of blotting paper or any similar substance, although one of the bearing plates should rest on a ball and socket joint to compensate for any slight angle between the planes of the surfaces of the specimen. Of course this bearing is not perfect unless the cylinders have been ground to planes, but it is believed that the error introduced by any such eccentric strains is less than the similar error occurring in tensile briquettes, whose bearings theoretically are never perfect.

From an academic standpoint the shape of these cylinders is defective in the ratio of diameter to height, but if either the diameter is decreased or the height increased the difficulties of uniform manipulation are much greater, and it is not believed that this practical objection would warrant increasing the height to about 1.5 times the diameter which is required by theory. A long series of tests showed that these cylinders gave strength values about 30 per cent. in excess of those obtained on 2-inch cubes.

Tests of these cylinders were made daily during the past winter in the Philadelphia laboratories, some of the results of which have been tabulated, and which have several features of interest.

As regards the uniformity of these tensile and compressive tests there is but little difference—the probable error of the individual tests averaging about 3 or 4 per cent. in both cases.

The tests first of all show the well known facts that the ratio

of compressive to tensile strength increases both with the age and the richness of the mortars. A most important difference, however, is found between the amount of this ratio and that given by most authorities. Johnson in his "Materials of Construction" gives for this ratio the value 8.64 + 1.8 times the logarithm of the age in months, this being based on a series of tests by Tetmajer on 1:3 mortars, which ratio is quoted by Taylor and Thompson, Sabin, and others as authoritative. Eckel says "it may be assumed that at the end of a year the average Portland cement mortar will have a compressive strength about ten times as great as its tensile strength." All writers in fact agree that this ratio should be from 8 to 12 for 1:3 mortars, although almost all obtain this from Tetmajer's tests and from some few by Chandlot and Feret.

These tests, however, show this ratio to average but slightly over 4 for the ordinary 1:3 mortar with quartz sand, the values being 3.98, 4.09, 4.37, and 4.45 for seven days, one, three and six months respectively, the highest value for any period being 5.75 and the lowest 2.93. Now these specimens were made from the same mortar, and were manipulated, stored and tested under identical conditions, which would have been impossible had 2-inch cubes been used, so that it is unlikely that any systematic error could have been made, while the number of tests, almost 2,000, is amply sufficient to give reliable data. Moreover, if the ratio be reduced to the basis of 2-inch cubes, it will be seen that it becomes only a little over 3. Or in other words the commonly assumed ratio of tensile to compressive strength of cement mortars is about three times as great as these tests show.

Another frequently made statement that tests in compression show a uniform increase in strength between different periods, is not borne out by these tests, the strengths in compression showing the common up and down values that are so familiar in tensile tests, and being of sufficient frequency and amount to preclude the possibility of being caused by error. Moreover the values do not go up and down together showing that not even for a single test can the ratio be considered a constant quantity, and that tensile and compressive strength are really entirely distinct properties and are only interdependent to a very slight degree.

It is to be hoped that more attention will be given to this important subject in the near future both to determine the average strength and ratio for purposes of design, and also to ascertain whether or not the compression test indicates better than the tensile test the true resistive properties of the cement, and hence whether it should supersede or at least be made in addition to the tensile test in routine laboratory work.

TABLE I.—COMPRESSION TESTS OF

No.	Brand.	Composition.	Kind of Sand.	7 Days.			28 Da	
				Tensile Strength.	Compressive Strength.	Ratio.	Tensile Strength.	Com press Streng
1	Portland. A	1:3	Standard Quartz	281	1129	4.02	352	139
2	B	"	"	285	1145	4.02	378	153
3	C	"	"	265	1104	4.17	345	140
4	D	"	"	196	718	3.66	275	112
5	E	"	"	155	600	3.87	241	102
6	F	"	"	225	672	2.99	301	91
7	G	"	"	242	920	3.80	308	104
8	H	"	"	266	1184	4.43	357	131
9	B	"	"	199	779	3.91	290	96
10	I	"	"	248	820	3.31	344	144
11	J	"	"	277	1001	3.61	343	14.
12	C	"	"	233	1070	4.59	303	14
13	H	"	"	242	868	3.59	323	11.
14	K	"	"	235	1085	4.62	338	13
15	F.	"	"	163	650	3.99	252	9
16	G	"	"	228	874	3.83	303	12
17	D	"	"	201	817	4.06	287	12
18	J	"	"	281	938	3.34	343	13
19	A	"	"	277	1248	4.51	350	14
20	L	"	"	283	1022	3.61	316	12
21	M	"	"	264	996	3.77	318	12
22	M	"	"	245	1029	4.20	330	14
23	I	"	"	274	946	3.45	337	13
24	M	"	"	243	880	3.62	345	11
25	B	"	"	235	984	4.19	281	14
26	N	"	"	222	953	4.29	297	14
27	J	"	"	221	970	4.39	342	14
28	I	"	"	267	1088	4.07	330	14
29	A	"	"	253	1081	4.27	315	15
30	I	"	"	213	833	3.91	298	13
31	E	"	"	153	880	5.75	259	13
32	A	"	"	235	845	3.60	313	11
33	H	"	Ottawa	310	1388	4.48	374	18
34	C	"	"	306	1037	3.39	361	17
35	I	"	"	326	918	2.82	376	19
36	B	"	"	315	1389	4.41	381	17
37	G.	"	"	326	1126	3.45	407	14
38	A	"	"	261	1018	3.90	318	15
39	M	"	"	305	1302	4.27	338	17
40	N.	1:2	Standard Quartz	415	1411	3.40	438	21
41	O.	"	"	191	834	4.37	283	11
42	N.	"	"	225	861	3.83	321	16
43	O.	"	"	202	1203	5.96	331	16
44	N	"	"	205	1271	6.20	345	18
45	N	"	"	201	929	4.62	319	15
46	N	"	"	197	807	4.10	308	11
47	N.	"	"	188	781	4.15	275	15
48	P	"	"	158	830	5.25	229	15
49	O.	Neat.	.....	275	2467†	8.97	340	31
50	P	"	.....	245	1619	6.61	362	25
51	N.	"	.....	211	1556	7.37	345	25
52	N.	"	.....	239	1692	7.08	337	24
53	N	"	.....	196	1751	8.93	303	25
54	N	"	.....	215	1318	6.13	320	19
55	O	"	.....	371	3100†	8.36	454	35
56	P	"	.....	275	2580†	9.38	368	30
57	O	"	.....	714	8535†	11.95	825	86
58	M	"	.....	720	4290†	5.96	791	66
59	K	"	.....	737	5457†	7.40	697	70
60	L	"	.....	782	7710†	9.86	783	90
61	C	"	.....	669	4393†	6.57	653	56
62	J	"	.....	847	8130†	9.60	868	74
63	H	"	.....	531	3572†	6.73	565	42
64	G.	"	.....	627	5232†	8.34	746	62
Average—Portland		1:3	St. Quartz	.....	.....	3.98	.....	.....
Portland		1:3	Ottawa	.....	.....	3.77	.....	.....
Natural		1:2	St. Quartz	.....	.....	4.81	.....	.....
Natural		Neat.	.....	.....	.....	7.85	.....	.....
Portland		Neat.	.....	.....	.....	8.30	.....	.....
Grand average		.....	.....	.....	.....	5.74	.....	.....

Notes.—All tests made by standard method. Each value based on three specimens. T
machine, except those marked † which were broken on "Universal" machine. Rate of stress,

ESTS OF ONE-INCH CYLINDERS.

	28 Days.		3 Months.			6 Months.		
e th.	Compressive Strength.	Ratio.	Tensile Strength.	Compressive Strength.	Ratio.	Tensile Strength.	Compressive Strength.	Ratio.
	1391	3.95	377	1672	4.44	316	1782	5.64
	1537	4.07	377	2066	5.48	358	2021	5.65
	1403	4.07	348	1693	4.86	341	1344	3.94
	1121	4.08	321	1406	4.38	354	1369	3.87
	1024	4.25	292	1345	4.61	313	1512	4.83
	911	3.03	341	1303	3.82	361	1483	4.11
	1041	3.38	369	1481	4.01	377	1553	4.12
	1316	3.69	371	1515	4.08	320	1329	4.15
	996	3.43	358	1345	3.76	386	1342	3.48
	1449	4.21	342	1462	4.80	367	1391	3.79
	1434	4.18	378	1629	4.31	368	1595	4.33
	1478	4.88	326	1459	4.48	327	1607	4.91
	1146	3.55	331	1501	4.53	329	1504	4.57
	1390	4.11	351	1758†	5.01	330	1777	5.38
	939	3.73	333	1094	3.29	412	1207	2.93
	1209	3.99	335	1523	4.55	499	1778	4.35
	1245	4.34	358	1414	3.95	365	1381	3.78
	1372	4.00	346	1420	4.10	365	1690	4.63
	1448	4.14	333	1665	5.00	385	1745	4.53
	1206	3.82	365	1494	4.09	334	1467	4.39
	1220	3.84	357	1486	4.16	321	1435	4.47
	1468	4.45	308	1573	5.11	307	1514	4.93
	1321	3.92	357	1527	4.28	353	1657	4.69
	1125	3.26	337	1547	4.59	350	1451	4.15
	1461	5.20	354	1196	3.38	323	1357	4.20
	1410	4.75	329	1501	4.56	363	1614	4.45
	1421	4.15	360	1317	3.66	354	1462	4.13
	1436	4.35	329	1879	5.71	337	1586	4.71
	1504	4.77	357	1466	4.11	314	1756	5.59
	1327	4.45	336	1433	4.26	314	1484	4.73
	1325	5.12	257	1226	4.77	259	1361	5.25
	1182	3.78	359	1272	3.54	375	1387	3.70
	1874	5.01	387	1719	4.44	339	2468†	7.28
	1760	4.88	399	1632	4.09	380	1755†	4.62
	1959†	5.21	473	2377†	5.03	419	2128†	5.08
	1753†	4.60	411	2168†	5.22	412	2082†	5.05
	1498	3.68	449	1733	3.86	382	2195†	5.75
	1558	4.90	431	1672	3.88	444	1988†	4.48
	1723†	5.10	447	1835	4.11	424	2148†	5.07
	2243†	5.12	485	1962	4.05	403	2683†	6.66
	1123	3.07	389	1856	4.77	527	2048†	3.89
	1613	5.02	461	1506	3.27	476	1828†	3.84
	1613	4.87	453	2090†	4.61	523	2347†	4.49
	1810	5.25	463	1942†	4.19	542	2708†	5.00
	1396	4.38	445	1755	3.94	526	2237†	4.25
	1125	3.65	439	1484	3.38	539	1448†	2.69
	1234	4.49	419	1633	3.90	492	1522†	3.09
	1208	5.28	341	1572	4.61	442	1955†	4.42
	3330†	9.79	413	4410†	10.68	445	5957†	13.39
	2225†	6.15	505	3910†	7.74	508	5100†	10.04
	2233†	6.47	389	2945†	7.57	406	3452†	8.50
	2442†	7.25	417	3062†	7.34	431	4560†	10.58
	2292†	7.56	369	4047†	10.97	407	4762†	11.70
	1953†	5.94	456	2728†	5.98	497	4203†	8.46
	3550†	7.82	538	4208†	7.82	499	6003†	12.03
	3088†	8.39	445	3838†	8.62	435	6383†	14.67
	8625†	10.45	799	8485†	10.62	753	11837†	15.72
	6987†	8.83	829	7647†	9.22	729	9090†	12.47
	7605†	10.91	763	6778†	8.88	690	11203†	16.24
	9475†	12.10	766	7057†	9.21	740	10988†	14.84
	5482†	8.40	663	6535†	9.86	715	9062†	12.67
	7477†	8.61	781	9083†	11.63	717	9413†	13.13
	4497†	7.96	594	7183†	12.09	560	7925†	14.15
	6183†	8.29	759	6005†	7.91	734	8563†	11.67
...	.....	4.09	.....	.....	4.37	.....	.....	4.45
...	.....	4.81	.....	.....	4.34	.....	.....	5.50
...	.....	4.61	.....	.....	4.08	.....	.....	3.96
...	.....	7.42	.....	.....	8.34	.....	.....	11.17
...	.....	9.44	.....	.....	9.93	.....	.....	13.86
...	.....	6.07	.....	.....	6.21	.....	.....	7.79

mens. Tensile tests made on "Fairbanks" machine, compression tests on "Olsen" cement
f stress, 600 pounds per minute.

DISCUSSION.

Mr. Thompson. MR. SANFORD E. THOMPSON.—Did Mr. Taylor make any comparative tests between these small cylinders and two-inch cubes?

Mr. Taylor. MR. W. P. TAYLOR.—Several series of tests were made to determine the ratio between these cylinders and two-inch cubes and it was found that the cubes had practically three-quarters of the strength of the cylinders for all periods and mixtures tried, showing the ratio to be almost entirely independent of the character of the material.

Mr. Talbot. MR. A. N. TALBOT.—I should like to ask Mr. Taylor a little further concerning the statement that an inch length of cylinder was found to be the most desirable. What would be the disadvantage of making the cylinder, say, twice as long as its diameter, or such an amount as would get us away from the shearing into pyramids which is obtained with ordinary cubes? I know it is accepted theory that the failure of these short prisms and cylinders is due to shearing action along a diagonal plane; but it is also thought that the friction of the bearing plates really causes this form of failure; and it is pretty well known that when the test piece is lengthened to an amount, say, twice as great as the diameter of the cylinder, the failure will be more of a splitting or crushing failure, there not being sufficient lateral strength to keep the piece from expanding laterally. If there is no objection to a greater length, would we not, in that way, get a better estimate of the real compressive strength of the material?

Mr. Taylor. MR. TAYLOR.—My objection to the higher cylinder is one of ordinary manipulation, it being almost impossible to compact under one pressure, a specimen whose depth is greater than one inch, so that if a greater depth is employed the difficulties of uniform manipulation are much increased. Moreover no distinct advantage is gained by its use, for the ratio between these and longer cylinders is so nearly constant that the error is small and in uniform ratio.

Mr. Merriman. MR. MANSFIELD MERRIMAN.—There is a committee of this Society—Committee K—which is charged with the investigation of methods of testing; and that, of course, includes the form of compression specimens. The paper presented to-day by Mr. Taylor will be of much service to that committee when it takes up the matter of cement, because there are so few series of tests on the compressive resistance of this material available. It is doubtful if the exact proportions of the specimen advocated by Mr. Taylor are those that will ultimately prevail; for it seems that the idea of facility in the preparation of the test specimen ought not to be the controlling one. The specimen ought rather to be of such proportions that failure may occur by diagonal shearing, since in this way the weak point of the material is developed; and this cannot be done unless the specimen is double the length of that used by Mr. Taylor.

Concerning the ratio of 8 or 10 between compressive and tensile strength, noted by him as not having been observed, I will say that in experiments at Lehigh University a similar conclusion has been derived. For a number of years compressive tests of cement have been made in our laboratory in connection with every tensile test, both on neat and mortar cubes, the neat cube being $1\frac{1}{2}$ and the mortar cube 2 inches in size. Notwithstanding the defects of the cube there is considerable to be said in its favor. It has been extensively used, and is to-day the form of specimen generally used in Europe, so that the comparison of international work is probably rendered more satisfactory from cubes than when it is endeavored to corrolate conclusions derived from specimens of different forms.

Mr. Brown. MR. S. A. BROWN.—I have made quite a number of compression tests in connection with the Market Street Subway, Philadelphia, and have noticed particularly the greater uniformity between compression test pieces.

If such a test as Mr. Taylor has described, could be incorporated in the "Uniform Tests for Cement," I think it would be highly desirable and better suited to the purpose than tensile tests.

Mr. Woolson. MR. IRA H. WOOLSON.—I want to say a word along the line that Mr. Merriman just spoke of, in regard to the form of test specimen to be used in this and other cases. My own experience has been that about 95 per cent., perhaps 98 per cent. of the test

specimens for compression on materials like stone, concrete, etc., coming into a testing laboratory as commercial work, are of the form of cubes; and unfortunately, to my mind, that has been the form of test specimens for a good many years. It is desirable, particularly from the commercial standpoint, to test cubes, because they are easily comparable with past work, as Professor Merriman has said, but I never make a test of that kind without an apology to myself at least, for making a test which I think is scientifically wrong. It seems to me that, in this connection, we ought to adopt and to give our favor every time to the form of specimen that we believe to be right, irrespective of what past practice has been. I think Mr. Talbot's point was very well taken, that it would be better to have the specimens for this character of test longer than the diameter, so as to bring out that shearing effect and do away with the possible effect of friction on the plates; and I agree with Professor Merriman, that for that purpose we ought not to let the question of difficulty in making the specimen interfere with the form of specimen. There is a disadvantage in the cube, I should think, in this kind of work, namely: the disadvantage of getting it out of the mold without possibly injury to the corners. It seems to me the cylinder is decidedly the best form. **Mr. Woolson.**

MR. TAYLOR.—I do not wish to be put on record as not recognizing the defects of these cylinders, but my claim is that in spite of these recognized defects this specimen is the best adapted to routine laboratory work. The common tensile briquette is known to be far from accurate, but it is used because it is more convenient than any other form developing a purer tensile stress. The same is true of this specimen, and any one who has had occasion to make a large number of compression tests will realize that uniform manipulation is far more readily obtained when cylinders instead of cubes are employed, while the same condition is found when short cylinders are compared with larger ones. The ratio between long cylinders and short ones, and between cubes and cylinders will be found practically constant and independent of the character of the material, so that if it is desired the compressive strength of a cube or deep cylinder may be computed from the results of these short cylinders with very little error, certainly far less than the error between the results from the common tensile briquette and the true strength of the material in pure tension. **Mr. Taylor.**

Mr. Humphrey.

MR. RICHARD L. HUMPHREY.—The compressive test of cement is one that the Committee on Uniform Tests of Cement of the American Society of Civil Engineers has had under discussion practically ever since it was appointed. There is a great deal to be said on the subject. One of the essentials in the adoption of any standard method for testing is the facility with which the test can be made, that is, convenience. It has been found that briquettes with square corners are much more difficult to mould than the briquettes in which these corners have been rounded off. The cylinders suggested by Mr. Taylor would probably therefore be more easy to mold than the cube. It is true also that the two-inch cube requires a greater mass of material. On the other hand, there are reasons why the cube is preferable to the cylinder, especially one as small as that proposed by Mr. Taylor. In introducing a new form of test-piece, there is, of course, always prejudice against it, especially the compression test since it is the practice to test cement largely in tension. Until the compression test has been used for a sufficient length of time to enable the operator to become familiar with it, it is quite likely that it will give irregular results. Uniformity is in my opinion more dependent on practice in the use of any given method than to variation in the form of test-piece. The difference in consistency of mortars will also largely offset the differences in the form of the test-piece. It is, however, quite certain that a great deal more work must be done on the compression test-piece before a method can be definitely established. It is the hope of the Committee on Uniform Tests of Cement that a method will be agreed on which can be reported on at the next meeting of the Society.

The Chairman.

THE CHAIRMAN (MR. R. W. LESLEY).—Possibly the questions I am about to ask do not apply so much to the actual results shown here on the subject of compression; but they do apply to two or three other things of interest. The paper, first of all, seems to confirm in a measure the theory of Michaelis, enunciated about a year ago, on the relation of the gain between the 7 and 28 day periods, between the tensile and compression tests. I do not know whether that relation has been plotted; but I feel very sure that if the hasty examination of these figures that I have made is any index the figures corroborate very largely that theory, namely: that in tension there is a different action than in com-

pression, and that the percentage of gain is generally larger in compression. I trust, if Mr. Taylor has the opportunity, before this paper is finally published he will plot this relation. I think that the facts will be found as I stated both for the mortar tests and for the neat Portland cement tests. **The Chairman.**

Again, I note at the bottom of the table a lot of Portland cement records running from about 700 to 850 pounds per square inch at 7 days and I also note some of the cements gave much lower values at 7 days. Is there any knowledge whether these cements are foreign or American?

MR. TAYLOR.—They are all American. **Mr. Taylor.**

THE CHAIRMAN.—The point I wish to make is that some of these lower cements seem to show larger gains, and also larger ratios, than some of the others. Tetmajer's figures which I studied a good many years ago—in 1896—were all based on the cements of that period all running between 400 and 500 pounds at 7 days and applied to cements made prior to the use of gypsum as a retardant of the setting properties of the alumina in rotary kiln cements and were all what is known to-day as very low-lime cements, many of them falling, I believe, outside of the modern hydraulic indices that the chemists of to-day use. If that is the case, and all those tests were made on the old style of dome-kiln cement, the ratio of that time between compression and tension may have been perfectly right; whereas, the present ratio applying to modern conditions might show an entirely different state of affairs. I think that might be brought out by a comparison of Mr. Taylor's figures with some of the original reports, issued by Professor Tetmajer at Zurich. I should like to ask whether the cements referred to as "natural" are natural cements, or what are known as "improved" cements, made in the Pennsylvania district? **The Chairman.**

MR. W. P. TAYLOR.—The first four are "improved" cements, the others natural. **Mr. Taylor.**

THE CHAIRMAN.—The table shows a very interesting state of facts: First, in the relatively high tensile strength of the 1 : 2 of the natural sand mortars compared with the 1 : 3 Portland cement mortars, the former at 28 days having practically the same and in many cases a higher tensile strength than the latter. In comparison the strength of the cement mortars does not **The Chairman.**

The Chairman. seem to be quite as high, though at the age of three weeks the results in comparison with the 1:2 natural mortars appear to be higher than that of the 1:3 Portland mortars, and at the age of six months the comparative strength of the former is much greater than that of the latter.

This calls to mind a point made by Mr. Stearns in the construction of the Clinton dam of the Metropolitan Water Board. In that case he had a large body of water to retain and the question of the greatest economy in a very large wall came in. With Portland cement he could build this wall of a certain width and stability; while with natural cement, which cost about half as much as Portland cement did at that plant, he could largely increase the width and the stability of the dam and in that way, at equal economy, get what he considered much the more substantial work.

Mr. Taylor's figures if plotted, and plotted with the relative cost of the two mortars, might indicate that for a great many pieces of work a natural cement could be used with equal safety as a Portland cement. By that I do not mean that in reinforced concrete, in floors, in exterior construction and in sidewalks, a natural cement could be substituted with safety; but these investigations, which, I trust will be carried out further, certainly demonstrate with the relative tensile and compressive strength of Portland, natural, and improved cements shown, that the cost of natural cement would be lower for a given strength.

Up to this date very few results of compression tests upon natural cements have been published. Engineers have known that in tension the values of natural cements were low; although their curve was a gradually ascending one rather than the rapidly ascending and then steadily declining curve of the Portland cements. There has been little knowledge of the compressive strength of natural cements and I think this investigation of that subject will throw a great deal of light on why the old natural cements of this country have given such wonderful results in practice, why they have been of such a permanent character, and why, wherever work done with natural cement had to be torn down, it had to be done by blasting. Mr. Taylor's results are very interesting and instructive and I trust a good many of the things suggested by this investigation may be ultimately worked

out more fully for the advancement of and knowledge concerning both classes of cement. **The Chairman.**

MR. LEE W. WALTER.—I should like to ask Mr. Taylor if in making tests of mortar to determine its comparative strength under tension and compression, he has used any sand other than the standardized crushed quartz? It occurs to me that the ratio of strength under compression and tension would differ materially by using different grades of sand. **Mr. Walter.**

MR. TAYLOR.—The ratio of tensile to compressive strength undoubtedly varies considerably with the character of the sand employed, as can be seen from the tests of the two grades of sand given in the table, although those made with Ottawa sand are not sufficient in number to give a definite ratio between the two. **Mr. Taylor.**

THE DETERMINATION OF THE SPECIFIC GRAVITY OF CEMENTS.

By Richard K. Meade.

Some time ago the writer undertook a series of experiments to determine the reliability of the various forms of apparatus now in common use, both in this country and abroad, for taking the specific gravity of cements. The result of this investigation is given below in the hope that it may prove of interest to the members of this Society.

As the first step to this investigation, four samples of cement were prepared by drying at 100° C. and passing through a No. 50 sieve. The specific gravity of each sample was then carefully determined by the use of a 50 cc. pycnometer or specific gravity bottle. Kerosene, freed from water by distillation over lime was employed for the liquid and the temperature was controlled to 0.1° C. The specific gravities of the samples were compared with water at 15° C. and were 3.088, 3.121, 3.193 and 3.240, respectively. The samples were kept in air-tight fruit jars.

The specific gravities of the four samples were then taken with LeChatelier's* apparatus, Jackson's† apparatus, McKenna's‡ apparatus and Schumann's§ apparatus. The results of these determinations were as follows: LeChatelier's apparatus gave results uniformly 0.01 too high. Jackson's apparatus gave results from 0.13 to 0.15 too low. McKenna's apparatus gave fairly satisfactory results. Schumann's apparatus gave satisfactory results.

The error in the case of the Jackson's apparatus seemed

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* Proceedings of the American Society for Testing Materials, Vol. IV, 1904. P. 112.

† Journal of the Society of Chemical Industry, June 15, 1904; also Engineering Record June 16, 1904.

‡ Journal of the American Chemical Society. XXI, 50 (1899).

§ See Butler's "Portland Cement."

most probably due to improper calibration of the flask and since all volumetric apparatus is likely to be incorrectly graduated all four forms of apparatus were examined to ascertain how carefully this had been done. The apparatus in all cases was freed from oil with benzine, ether, alcohol and water, in the order

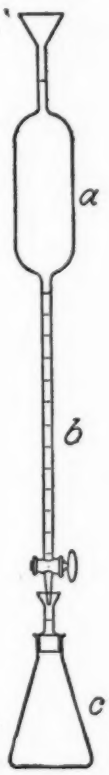


Fig. 1.

Fig. 2.

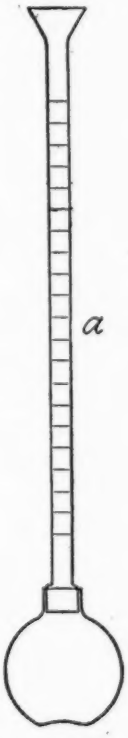


Fig. 3.

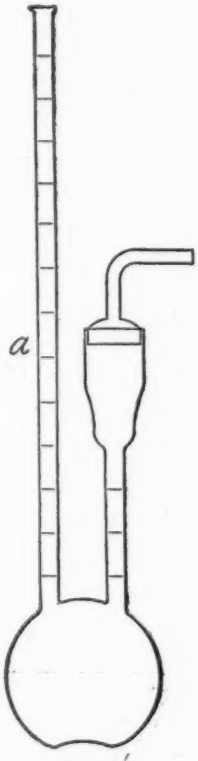


Fig. 4.

named, freed from cement particles by washing with a little hot dilute hydrochloric acid, and from dust, etc., by allowing a mixture of potassium bichromate water and sulphuric acid to stand in it over night. After washing and drying it was calibrated.

In the LeChatelier apparatus, Fig. 2, the bulb, *b*, should hold exactly 20 cc. and the stem, *a*, between the graduations 0 and 3 should hold 3 cc. The bulb of the apparatus tested held

20.05 cc. at 70° F., or an error of 0.05 cc. The graduations on the stem were found to be accurate, consequently the total error amounted to 0.05 cc. and this amount (equivalent to an error of about 0.008) was added to each reading in making a determination with this particular LeChatelier apparatus.

In the Schumann apparatus, Fig. 3, the stem, *a*, is graduated into 40 cc. and these again into tenths cc. These graduations were found to be accurate.

In the Jackson apparatus, Fig. 1, the bulb, *a*, of the burette should hold 180 cc. and the stem, *b*, 5.71 cc. The flask, *c*, should hold 200 cc., or if the burette bulb holds less or more than 180 cc., it should hold the contents of the bulb plus exactly 20 cc.

The flask of the apparatus in question held the contents of the burette bulb plus 19.3 cc., or an error of 0.7 cc. (equivalent to an error of from 0.12–0.15 in specific gravity). The graduations on the stem were found to be correct.

All of the apparatus was calibrated by running in water or kerosene from a calibrated 25 cc. burette, graduated into $\frac{1}{20}$ cc. and easily read to $\frac{1}{40}$ cc.

The flask of the Jackson apparatus was then recalibrated by adding 20 cc. of water from the burette and then the bulb of the Jackson burette full (180 cc.) of water.

Determinations made with the recalibrated Jackson apparatus and by applying the correction to the LeChatelier apparatus, were very satisfactory as the following table will show:

TABLE OF RESULTS.

Cement No.	1	2.	3	
Form of apparatus used.				
Pycnomiter	3.193	3.088	3.121	3.240
Jackson's	3.19	3.09	3.12	3.23
LeChatelier's	3.20	3.09	3.12	3.24
McKenna's	3.19	3.08	3.13	3.25
Schumann's	3.19	3.09	3.12	3.24

To guard against improperly calibrated specific gravity apparatus, the tester should either check the volume of the bulb of the LeChatelier apparatus and of the flask of the Jackson apparatus or else request the maker of the apparatus to furnish

with the same a certificate from the U. S. Bureau of Standards testifying to its trustworthiness. Of the four forms of apparatus, three are affected by any change in the temperature of the liquid between the two readings. With the Jackson apparatus, a table is supplied which gives the correction to be applied. In the other forms of apparatus, precautions are usually taken to guard against changes in temperature, such as immersing the instrument in a jar of water. The coefficient of expansion of kerosene is 0.0009 per degree C., or 0.0005 per degree F. The LeChatelier apparatus has a volume of 130 cc., consequently the expansion due to a rise of one degree C. amounts to 0.12 cc., after deducting for the expansion of the glass, or an error of approximately .018 in specific gravity.

The Schumann apparatus holds from 110 to 150 cc. and hence has about the same error. The McKenna apparatus, however, has a volume of 300 cc. and, since the stem is graduated into only 11 cc., the sample is smaller (between 30–35 grams) than that used for either the LeChatelier or the Schumann apparatus. The expansion per degree C. rise with this apparatus amounts to 0.27 cc., or an error of approximately 0.07 in specific gravity. Dr. McKenna has now improved his apparatus by blowing a thermometer into the bulb between the two tubes allowing temperature corrections to be easily made. The bulb itself is much smaller, doing away with the large error due to expansion, and the graduated tube is narrower and longer making the apparatus much more delicate.

Since it is by no means an easy matter to keep the temperature constant during a determination, unless water, oil, cement and apparatus are allowed to remain side by side for some time, I have usually found it more convenient to take the temperature of the oil just before bringing it to the zero point and just after making the final reading. With the LeChatelier apparatus 0.12 cc. is then deducted from the final reading for every degree C. rise or added for every degree drop in temperature of the second reading over the first.

The chief objection I have found to the standard LeChatelier apparatus is the time and care necessary to run the cement into the apparatus. The same objection holds good for both the Schumann and McKenna forms of specific gravity apparatus.

McKenna's apparatus must also be protected from even slight changes of temperature, and requires a higher degree of manipulative skill than any of the other three forms. The Jackson apparatus is much more convenient than any of the others and is just as accurate provided it is properly graduated. This latter

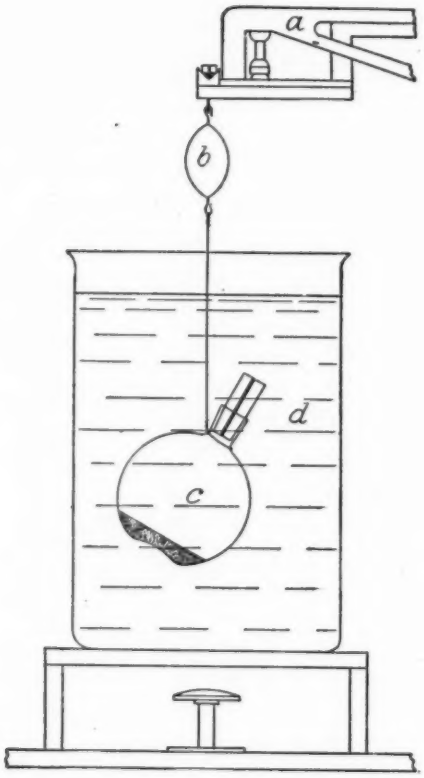


Fig. 5.

may be made sure of, as I have suggested, by having it certified to by the U. S. Bureau of Standards. The makers could have this done at small cost in lots of ten or more. The greatest objection to the Jackson apparatus when properly graduated is the necessity of drying the flask before each determination. This can be avoided by graduating the flask wet (with kerosene), say after

draining two minutes in an inclined position so as to allow the bottom also to drain and removing the suspended drop. Flasks so graduated give just as accurate results as do dry flasks and time may be saved by using the wet flask.

It is sometimes necessary to take the specific gravity of samples of cement after ignition at a low red heat. With the appliances at hand in the ordinary cement testing laboratory it is a difficult matter to ignite more than 5 or 10 grams at one time. None of the forms of apparatus ordinarily used for taking the specific gravity of cement is suited to the use of such a small sample. For this purpose I have used the method given below:

From one arm, *a* (the left), of the balance take off the balance pan and in its place suspend from the stirrup, as shown in Fig. 5, a 50 gram weight, *b* (or any weight sufficient to more than balance this pan such as a lead fishing sinker). Take the weight of this on the other pan and call this weight "A." Now attach to this by a fine silk thread or wire a 50 or 100 cc. pycnometer, *c* (a small 100 cc. Erlenmeyer flask with a narrow mouth will also do). Weigh the pycnometer so suspended and call the total weight "B." B–A will then be the weight of the pycnometer in air. Now fill the pycnometer with water in the usual way carefully forcing out all air and weigh suspended in a tall narrow beaker or jar, *d*, of water. Call this weight "C." "Loss in water" = (B–A)—(C–A). Now dry the pycnometer, fill with oil and weigh suspended in kerosene. Call this weight "D." "Loss in kerosene" = (B–A)—(D–A)

$$\text{Specific gravity of the kerosene} = \frac{\text{"Loss in kerosene"}}{\text{"Loss in water"}}$$

Now remove the pycnometer and pour out half of the kerosene, introduce W (usually 5 to 10) grams of the ignited cement and mix thoroughly by twirling around the contents of the pycnometer. Fill the pycnometer to the neck with oil and allow a few minutes for the contents to settle. Fill the neck full by pouring down the sides, suspend in kerosene and weigh as before. Call weight "E."

$$\text{Specific gravity of the cement} = \frac{\text{W} \times \text{specific gravity of the oil}}{(\text{W} + \text{D}) - \text{E}}$$

The temperature of the oil should not change more than 2° C. during the time between the taking of its own density and that of the cement. The weight of the pycnometer suspended in water need be taken but once. After this is done a determination can be easily made in ten minutes. Even the finest particles of the cement settle in a few minutes and results obtained by the method are very trustworthy, as the following will show:–

Sample No.	Pycnometer Method.	Suspension Method.
1	3.193	3.190
2	3.088	3.086
3	3.121	3.120
4	3.240	3.241
5	3.135	3.136
6	3.027	3.026

An example of the calculation is given below:–

Weight to balance (A)	11.823
Weight of pycnometer suspended to the above in air (B)	40.825
Weight of pycnometer suspended to the above in water (C)	29.181

"Loss in water" = (B-A)–(C-A) = (40.825–11.823)–(29.181–11.823) = 11.644.

(The above are permanent results and provided the same pycnometer or flask is used for each determination need be obtained but once.)

Weight of pycnometer suspended in kerosene (D) 31.662

"Loss in oil" = (B-A)–(D-A) = (40.825–11.823)–(31.662–11.823) = 9.163.

$$\text{Specific gravity of oil} = \frac{\text{Loss in Oil}}{\text{Loss in Water}} = \frac{9.163}{11.644} = 0.737$$

Weight of pycnometer + 10 grams of cement suspended in kerosene (E) 39.152

$$\text{Specific Gravity of Cement} = \frac{W \times \text{Sp. Gravity of Oil}}{(W+D) - E} =$$

$$\frac{10 \times 0.787}{(10+31.662) - 39.152} = \frac{7.87}{2.510} = 3.136.$$

SOME SAND EXPERIMENTS RELATING TO PER CENT. OF VOIDS AND TENSILE STRENGTH.

By J. Y. Jewett.

The accompanying tabulation shows the results obtained from a series of tests recently made at the Denver Cement Testing Laboratory, United States Reclamation Service, with relation to the per cent. of voids and tensile strength of mixtures of sands of varying degrees of fineness and coarseness.

Object of Tests.—These experiments were suggested by some rather unexpected results obtained for per cent. of voids in various sands tests made during the past year at this laboratory and it was thought that some interesting results might be obtained by making up a number of sand mixtures by a process of assortment of a selected sand into grains of various sizes and then mixing these together in various proportions to see what mixtures would give the lowest per cent. of voids. The tests for tensile strength were made to see what relation exists between the per cent. of voids and the tensile strength, it being generally considered that sand with a low per cent. of voids will give a higher tensile strength than would be obtained with a sand of the same quality but having a higher per cent. of voids.

It has been the writer's experience that as a general rule coarse sands give a higher tensile strength than the finer grades and in the tests above alluded to it was noted that some extremely coarse sands gave better results for tensile strength than other sands such as are generally spoken of as being well graded with grains of various sizes and which are generally considered preferable on that account. Therefore, another object in making the tests here described was to see how far this coarseness could be carried to good advantage, both with relation to the per cent. of voids and the tensile strength.

Material Used.—The sand used for these tests was obtained from the bed of Clear Creek, near Denver, and after being dried was separated from the gravel with which it was mixed by screen-

ing on a No. 4 sieve. It was then separated by screening into six different sizes, as shown by the accompanying table, the mixtures being subsequently made in proportions as there shown.

It may be noted here that this sand was all obtained from the same place in the creek bed and was all of the same quality, the various portions differing only in size of grain, the finer portions having a similar appearance when viewed under a magnifying glass to that of the coarser portions when seen by the naked eye. This is considered to be an important point in connection with the experiments, making them more nearly comparable than would otherwise be the case.

With regard to the range of fineness and coarseness of the material, it may be noted that of the portion passing the No. 100 sieve, about 25 per cent. would pass the No. 200 sieve, while of that passing the No. 4 sieve and held on No. 10, a large proportion, as far as could be judged by observation, would range nearer the No. 4 sieve than the No. 10. In fact, this portion taken by itself might almost be classed as fine gravel.

The cement used was of the Iola brand and gave tests as follows:

Per cent Passing Sieve.		Initial Set.	Final Set.		Tensile Strength. Lbs. per sq. in.		
No. 100.	No. 200.	Hours.	Hours.		7-day.	28-day.	3-month.
95.0	75.0	4.30	9.00	Neat	635	769	870
				Standard Sand, 3 to 1	306	403	486

Methods Used.—The method used for determining the per cent. of voids was recommended to the writer by Mr. R. L. Humphrey of the Structural Materials Testing Laboratory, United States Geological Survey, St. Louis, Mo., and was described by him as follows; this being an improvement over the method of pouring water into a vessel containing the sand as it eliminates all error caused by bubbles of air being caught and held in the sample under test:

"The apparatus consists of a percolator about three inches in diameter and eight inches long, having a funnel-shaped orifice at the bottom,

which is connected by a rubber tube to a graduated burette. A small perforated porcelain disk fits over the opening in the percolator, in which is placed a given quantity of the material, filling it up to a mark of a definite volume. The burette is read; the water is then allowed to gradually enter the percolator from the bottom until it reaches the upper mark. The difference in the readings of the burette gives the quantity of the water required to fill the voids."

It may be noted as a matter of detail in using this method that the writer found it more convenient to fill the percolator to the top rather than to a mark on the side, in which case the sand can be struck off even with a straight-edge, and a piece of glass placed over the top very readily shows when the water has reached the exact level required.

In all measurements the sand was measured loose and not compacted in any way.

In the 3 to 1 tensile tests the proportions are by volume, not by weight, the relation between weight and volume of the cement being taken at 100 pounds per cubic foot.

The consistency of the mortar in making the tensile tests was made to approximate as closely as possible the "normal consistency" of the regular tests of cement with standard sand, and in filling the molds the material was pressed in firmly with the fingers and finished off with a trowel without ramming. The figures given for tensile strength are in each case the average of three briquettes for the period in question, while the results given for per cent. of voids are in each case the average of two determinations, except when these did not give a close enough check, in which case a third determination was made.

With regard to the method employed in making up the various mixtures of sand used, it may be said that in considering the method to be employed the fact was recognized that there was an almost unlimited number of different mixtures that could be made. It seemed desirable, however, to make up the mixtures according to some regular system and not in a haphazard manner. It seemed desirable also to have them include as wide a range as possible, not only of well graded mixtures, but of extremes of coarseness and fineness and, in fact, of mixtures in which each of the six grades used would be largely in excess. It will be noticed from the table that the various mixtures made are arranged in

groups. For instance, in the first group a start is made with 10 per cent. of the portion passing sieve No. 4 and held on No. 10. The remaining 90 per cent. is then divided into fifteen equal parts, five of these, or 30 per cent., being assigned to the next portion, four to the next and so on to the end. The next step is to assign the 10 per cent. to the second portion or that passing the No. 10 sieve, and held on No. 20, moving each of the other percentages along one place, as shown by the table. This process is continued for all six portions and then the 10 per cent. is again assigned to the first portion, as shown in the second group in the table, and the position of the other 5 percentages is reversed, beginning with the smaller and running up to the larger, and the series is made up by moving each percentage forward one place in succession as before. After this 10 per cent. double series was completed, similar ones were made with 20 per cent., 40 per cent. and 70 per cent., concluding with 100 per cent. of each portion. Also partial series, starting with 50, 60, 80 and 90 per cent. respectively, were made, these being included especially to show how far coarseness of grain could be carried to good advantage as already spoken of, when describing the object of these tests. The 30 per cent. series was omitted altogether, as it would give mixtures not materially different from the 10 per cent. series.

Results Obtained.—In tabulating the results obtained, columns have been inserted in the table, showing the "relative position" of each mixture as to the per cent. of voids from the lowest to the highest and for tensile strength from the highest results to the lowest.

With regard to the results obtained for per cent. of voids, it may be noted that of the sixteen mixtures giving less than 35 per cent. of voids, four of these, Nos. 6, 25, 37 and 41, are in general what might be called well graded sands, although the two latter are rather coarse, while the other twelve, Nos. 5, 8, 9, 17, 18, 20, 21, 31, 32, 39, 43 and 51, each contain comparatively large proportions of the coarse and fine grades with correspondingly small proportions of the medium grades.

It will be noticed also that there is quite a marked difference in "relative position" between the mixtures giving the lowest per cent. of voids and those giving the highest tensile strength, and it would seem that there is not such a close relation between the

two as there has sometimes been considered to be, the tensile strength apparently being more largely dependent on the coarseness of grain than on a low per cent. of voids. Thus in making a comparison between the sixteen mixtures already mentioned as giving the lowest per cent. of voids and the sixteen mixtures giving the highest tensile strength which are:

7-day, Nos. 6, 9, 25, 37, 40, 41, 45, 51, 57, 59-65.
28-day, Nos. 6, 25, 32, 37, 40, 41, 44, 45, 51, 57, 59, 61-65.
3 month, Nos. 6, 25, 33, 37, 41, 45, 51, 57-65,

it may be noted that of the former list the following numbers only are included in the latter list:

7-day, Nos. 6, 9, 25, 37, 41, 51.
28-day, Nos. 6, 25, 32, 37, 41, 51.
3-month, Nos. 6, 25, 37, 41, 51.

While the numbers making up the latter list are without exception the coarsest sands in the lot, No. 65 which marks the extreme of coarseness having a relative position of 4, 8 and 11 for 7 days, 28 days and 3 months respectively, but at the same time having a relative position of 64 with relation to the per cent. of voids.

It is quite possible, however, that while coarseness of grain tends to produce a high tensile strength a better graded sand might produce a mortar of greater density and one that would give higher results in compression tests than the coarser grades, and it is to be regretted that compression tests were not available for comparison with the tensile tests here reported, especially in connection with some of the more important mixtures.

Therefore, in conclusion, it may be said that while these experiments may not be as complete as could have been desired, still it is hoped that they may be of some interest along the lines indicated, and may add a little to the information already at hand from the various investigations that have been made in regard to the best grades of sand for use in the works of engineering construction into which this material enters.

Appendix.

Since the foregoing paper was written tests for compressive strength and permeability have been made on some of the more representative mixtures included in the above table the results of which are herewith added to the results there given.

The compression tests were made at the Structural Materials Testing Laboratory of the U. S. Geological Survey at St. Louis, Mo., six samples of sand being sent there for that purpose and a supply of cement also being furnished from the same lot used for the tensile tests in the above mentioned table. The results obtained are as follows, the figures given being in each case the average of three specimens tested for the period in question:

Sample.	Compressive Strength. Pounds per sq. in.—3 to 1 (by Vol.).		
	7 days.	28 days.	3 mos.
No. 12, Medium	861	1,322	1,833
" 25, "Well graded"	1,284	2,335	4,150
" 39, Lowest per cent. of voids (mixture of coarse and fine)	920	1,718	3,050
" 41, Coarse	1,619	2,406	4,108
" 56, Fine	413	1,219	1,742
" 65, Extremely coarse	669	1,589	3,800

The permeability tests have not been very extensive and it will hardly be in order to give a detailed description here of the apparatus used. Briefly stated, however, the apparatus consists of cast iron cylinders containing a core of mortar 20 in. high and 6 in. in diameter connected with the city water system in such a way that water pressure from the system can be applied to the top of the cylinder of mortar and measurements taken at the bottom of the amount of water coming through in a given time, giving the rate of percolation in cc. per hour, this method being similar to that used for an extensive series of experiments made in this line in connection with the Metropolitan Water Works of Massachusetts, at Clinton, Mass., at which place the writer was located before coming to his present position.

TABLE I.

No. of Test.	Composition of Mixture.						Voids.		Tensile Strength, Pounds per Square Inch. 3 to 1 (by Vol.).					
									7 Days.		28 Days.		3 Months.	
	Per Cent. Passing Sieve No. 4 and held on No. 10.	Per Cent. Passing Sieve No. 10 and held on No. 20.	Per Cent. Passing Sieve No. 20 and held on No. 30.	Per Cent. Passing Sieve No. 30 and held on No. 50.	Per Cent. Passing Sieve No. 50 and held on No. 100.	Per Cent. Passing Sieve No. 100.	Per Cent.	Relative Position.	Tensile Strength.	Relative Position.	Tensile Strength.	Relative Position.	Tensile Strength.	Relative Position.
1	10.0	30.0	24.0	18.0	12.0	6.0	36.8	23	210	37	349	32	451	27
2	6.0	10.0	30.0	24.0	18.0	12.0	39.5	43	199	46	333	45	393	49
3	12.0	6.0	10.0	30.0	24.0	18.0	38.8	40	220	34	324	54	434	31
4	18.0	12.0	6.0	10.0	30.0	24.0	37.9	33	209	38	335	43	345	65
5	24.0	18.0	12.0	6.0	10.0	30.0	33.6	4	251	17	338	40	413	42
6	30.0	24.0	18.0	12.0	6.0	10.0	33.7	5	299	7	400	16	491	15
7	10.0	6.0	12.0	18.0	24.0	30.0	38.9	41	187	56	328	50	354	62
8	30.0	10.0	6.0	12.0	18.0	24.0	34.9	16	224	33	325	53	343	66
9	24.0	30.0	10.0	6.0	12.0	18.0	33.8	6	252	16	385	20	447	29
10	18.0	24.0	30.0	10.0	6.0	12.0	35.6	18	242	23	358	31	460	25
11	12.0	18.0	24.0	30.0	10.0	6.0	38.2	35	234	28	360	29	430	34
12	6.0	12.0	18.0	24.0	30.0	10.0	39.3	42	229	31	334	44	367	58
13	20.0	26.7	21.3	16.0	10.7	5.3	36.0	20	183	59	359	30	441	30
14	5.3	20.0	26.7	21.3	16.0	10.7	37.2	27	182	60	332	46	417	39
15	10.7	5.3	20.0	26.7	21.3	16.0	38.4	37	201	44	339	39	384	51
16	16.0	10.7	5.3	20.0	26.7	21.3	37.1	26	203	42	331	47	375	54
17	21.3	16.0	10.7	5.3	20.0	26.7	34.4	12	215	36	337	41	416	40
18	26.7	21.3	16.0	10.7	5.3	20.0	34.5	13	194	50	378	22	431	33
19	20.0	5.3	10.7	16.0	21.3	26.7	37.4	28	172	64	306	61	371	56
20	26.7	20.0	5.3	10.7	16.0	21.3	33.9	7	216	35	365	27	392	50
21	21.3	26.7	20.0	5.3	10.7	16.0	34.2	10	200	45	386	19	462	24
22	16.0	21.3	26.7	20.0	5.3	10.7	36.1	21	227	32	381	21	455	26
23	10.7	16.0	21.3	26.7	20.0	5.3	38.6	38	236	26	363	28	433	32
24	5.3	10.7	16.0	21.3	26.7	20.0	40.5	49	185	58	327	51	402	48
25	40.0	20.0	16.0	12.0	8.0	4.0	34.0	8	264	12	410	14	490	16
26	4.0	40.0	20.0	16.0	12.0	8.0	37.7	31	235	27	344	36	428	35
27	8.0	4.0	40.0	20.0	16.0	12.0	38.7	39	181	61	323	55	405	45
28	12.0	8.0	4.0	40.0	20.0	16.0	39.7	45	168	65	290	65	320	69
29	16.0	12.0	8.0	4.0	40.0	20.0	38.3	36	198	47	315	59	348	63
30	20.0	16.0	12.0	8.0	4.0	40.0	35.7	19	196	48	336	42	383	52
31	40.0	4.0	8.0	12.0	16.0	20.0	33.2	2	238	25	347	33	404	46
32	20.0	40.0	4.0	8.0	12.0	16.0	34.3	11	241	24	421	10	481	19

29	16.0	12.0	8.0	4.0	40.0	20.0	38.3	36	198	47	315	59	348	63
30	20.0	16.0	12.0	8.0	4.0	40.0	35.7	19	196	48	336	42	383	52
31	40.0	4.0	8.0	12.0	16.0	20.0	33.2	2	238	25	347	33	404	46
32	20.0	40.0	4.0	8.0	12.0	16.0	34.3	11	241	24	421	10	481	19
33	16.0	20.0	40.0	4.0	8.0	12.0	36.3	22	250	18	387	18	499	14
34	12.0	16.0	20.0	40.0	4.0	8.0	38.0	34	202	43	343	37	421	38
35	8.0	12.0	16.0	20.0	40.0	4.0	39.9	47	205	41	330	48	406	44
36	4.0	8.0	12.0	16.0	20.0	40.0	41.1	51	186	57	312	60	369	57
37	50.0	16.7	13.3	10.0	6.7	3.3	34.6	14	284	9	412	13	542	7
38	3.3	50.0	16.7	13.3	10.0	6.7	37.8	32	230	30	345	35	482	18
39	50.0	3.3	6.7	10.0	13.3	16.7	32.5	1	244	21	370	25	426	37
40	16.7	50.0	3.3	6.7	10.0	13.3	35.3	17	279	10	408	15	477	21
41	60.0	13.3	10.7	8.0	5.3	2.7	34.7	15	345	2	441	6	587	1
42	2.7	60.0	13.3	10.7	8.0	5.3	37.6	30	246	20	372	24	472	22
43	60.0	2.7	5.3	8.0	10.7	13.3	33.3	3	207	39	322	56	410	43
44	13.3	60.0	2.7	5.3	8.0	10.7	36.9	24	249	19	416	12	464	23
45	70.0	10.0	8.0	6.0	4.0	2.0	37.5	29	255	13	460	3	562	3
46	2.0	70.0	10.0	8.0	6.0	4.0	41.2	52	192	52	346	34	448	28
47	4.0	2.0	70.0	10.0	8.0	6.0	41.8	56	174	63	295	63	363	59
48	6.0	4.0	2.0	70.0	10.0	8.0	41.6	55	193	51	271	69	347	64
49	8.0	6.0	4.0	2.0	70.0	10.0	42.5	57	167	66	289	66	331	68
50	10.0	8.0	6.0	4.0	2.0	70.0	41.4	53	195	49	297	62	356	61
51	70.0	2.0	4.0	6.0	8.0	10.0	34.1	9	253	15	426	9	545	6
52	10.0	70.0	2.0	4.0	6.0	8.0	39.6	44	243	22	390	17	489	17
53	8.0	10.0	70.0	2.0	4.0	6.0	43.0	59	180	62	329	49	415	41
54	6.0	8.0	10.0	70.0	2.0	4.0	43.3	60	191	53	321	57	403	47
55	4.0	6.0	8.0	10.0	70.0	2.0	43.6	61	190	54	320	58	382	53
56	2.0	4.0	6.0	8.0	10.0	70.0	45.5	65	188	55	278	67	339	67
57	80.0	6.7	5.3	4.0	2.7	1.3	40.4	48	307	6	488	2	530	10
58	1.3	80.0	6.7	5.3	4.0	2.7	42.6	58	233	29	326	52	524	12
59	80.0	1.3	2.7	4.0	5.3	6.7	37.0	25	320	5	442	5	583	2
60	6.7	80.0	1.3	2.7	4.0	5.3	41.5	54	287	8	369	26	531	9
61	90.0	3.3	2.7	2.0	1.3	0.7	40.7	50	344	3	502	1	559	4
62	0.7	90.0	3.3	2.7	2.0	1.3	43.7	62	254	14	420	11	522	13
63	90.0	0.7	1.3	2.0	2.7	3.3	39.8	46	353	1	450	4	539	8
64	3.3	90.0	0.7	1.3	2.0	2.7	43.9	63	266	11	434	7	550	5
65	100.0	.....	.....	.....	.....	.....	44.4	64	330	4	432	8	529	11
66	.....	100.0	.....	.....	.....	.....	47.5	66	206	40	375	23	480	20
67	.....	.....	100.0	.....	.....	.....	49.7	67	166	67	342	38	427	36
68	.....	.....	.....	100.0	.....	.....	50.0	68	135	70	294	64	358	60
69	.....	.....	.....	.....	100.0	.....	50.1	69	146	69	275	68	373	55
70	.....	.....	.....	.....	.....	100.0	50.2	70	154	68	270	70	309	70

It was well known from the tests made there that a sand of a coarseness such that 50 per cent. or more would be included in the portion passing a No. 8 sieve and held on a No. 30 would give good results in this line. Therefore, Sample No. 26 was taken as a representative sample of this class and tests for a comparison with it were made on Nos. 41 and 65 to get some idea of how much farther, if any, the coarseness could be carried with good results as to permeability. As to the results obtained, No. 41 gave a somewhat lower rate of percolation than No. 26, but in the case of No. 65 there was a very large flow, the water passing through in a large stream with apparently but little diminution in force.

These additional tests for compression and permeability taken in connection with the results previously reported would seem to show that Sample No. 41 is about the limit to which coarseness can be carried to good advantage, this sample giving as a whole the best results of any under consideration here.

It would seem from the results of the foregoing tests that a low per cent. of voids alone does not give much indication of the value of a sand unless accompanied by coarseness of grain, and, also, that requirements calling for a well graded sand might well be modified to call for a sand graded from coarse to fine with the coarse grains largely predominating in amount, such as are represented by Nos. 25, 37 and 41 of the foregoing series.

DISCUSSION.

Mr. Brown. MR. S. A. BROWN.—I should like Mr. Humphrey to kindly describe in detail the method he uses for obtaining voids.

Mr. Humphrey. MR. RICHARD L. HUMPHREY.—The apparatus referred to by Mr. Jewett in his paper is one of several which we are trying at St. Louis. It consists of a percolator of glass, having a porcelain cap fitting over the outlet at the bottom. The burette provided with a stop cock, contains the water which is used. The burette is connected to the bottom of the percolator by means of the rubber tube. The percolator is filled with sand or the material from which the percentage of voids is to be obtained either to a given mark or to the top. The water is allowed to flow in from the burette through the tube, and in rising in the percolator drives out the air of the quantity required to fill the percolator to the top, representing the voids in the materials under test. As indicated by Mr. Jewett, better results can be obtained by bringing the sand up to the top of the percolator and filling with water to that point than to attempt to bring the sand and water to a given point. The great trouble in determining the percentage of voids is to get the entrained air out of the mass of sand. It is almost impossible to pour water in from the top of a vessel so as to get this air out, and the most efficient way seems to be to pour the water from the bottom of the vessel. We also tried to sieve the material into a jar of water and observe the increase in volume due to the admission of a given quantity of material, but careful comparison of this method with the percolator gave practically concordant results, besides the percolator is much more convenient. The more accurate way of determining the percentage of voids is to get the specific gravity of the materials and from this calculate the voids in a given weight of the same material. We are making both determinations at St. Louis.

Mr. Brown. MR. BROWN.—If you pour the sand into the vessel containing the water is not the air thoroughly driven out, which produces a readjustment of the particles, causing shrinkage in volume?

Mr. Humphrey. MR. HUMPHREY.—I think that is quite true, but it should be remembered that there is a given amount of material to be tested

and the amount of water required to fill the vessel up to the level of the material before the water is admitted represents the total voids in that material in the loose state. No matter what kind of sand is used and no matter how carefully the tests are made there will always be more or less shrinkage in the volume. Mr. Humphrey.

MR. BROWN.—There has always been a question in my mind as to whether the voids should be calculated upon the original volume used at the beginning of the test or the readjusted volume. It seems to me that in concrete where the water is sufficient to allow a movement of the particles that this readjustment would take place with a consequent reduction of voids. Such a readjusted volume should be used as the basis for calculation. Mr. Brown.

In experiments with different sands I have noticed that in allowing the sand to settle through the water, a graded sand would decrease considerably in volume, while a uniform sand tested under the same conditions would remain about the same in volume.

MR. W. B. FULLER.—I would question the accuracy of the determination of voids in sand by any means of measuring with water, and am accordingly inclined to view with doubt conclusions as to relative values of mortars based on such determinations. Mr. Fuller.

Voids determined by the water method, even if accurately determined, represent the voids only under one condition and that condition is entirely distinct from the arrangement of the particles of sand as they occur in mortars. I have made many tests on sands which are found in the vicinity of New York City under different conditions of contained moisture and packing and find such sands to weigh anywhere from 80 to 120 pounds per cubic foot, although the specific gravity of the sand particles is alike in all cases.* In other words identically the same sand will have from 25 to 50 per cent. voids depending on the conditions of measurement.

It is quite possible that the sands as represented in the author's tables as having the least amount of voids may not have the least amount of void when mixed in the form of mortar.

To my mind the scientific way of comparing different mortars and concrete is to weigh all the material entering into its composition and after determining its set volume to calculate from

*See Taylor and Thompson's Treatise on Concrete, Plain and Reinforced, pp. 176-178.

Mr. Fuller. the known specific gravity of the materials the density of the specimen (that is the total amount of solid ingredients it contains).

This insures a knowledge of the absolute volume of each ingredient and thus a knowledge of the remaining void and I believe as a result of my experience with New York City sands that a comparison on such a basis would bring out laws of value to other experimentors along the same line.

Mr. Taylor. MR. W. P. TAYLOR.—I would like to corroborate in every respect what Mr. Fuller has said. The only proper condition in which sand can be tested for voids is after first drying it to a fixed temperature of a little over 212° F., and if that is done and water is added, the amount of water absorbed during the process is so great as to entirely upset any calculation; whereas, if the sand is first dried and then put into a cylinder or some similar receptacle under a uniform compacting or jarring it is possible to get very uniform and accurate determinations on these tests by means of a simple weighing.

Mr. Walters. MR. L. W. WALTERS.—I agree with Mr. Taylor in his remarks as regards the advisability of drying sand in all cases before determination is made for percentage of voids. I have made extensive experiments to determine the comparative volume of mortar resulting from using sand by measure wet on one hand and dry on the other; and I would say that the volume of resulting mortar runs usually from 10 to 15 or 16 per cent. higher by using the dried sand by measure than by using the same sand wet by measure without compressing. This would indicate that the percentage of voids in wet sand is much greater than in the same sand if dried; and from this fact I think it is important that in determining the percentage of voids in sand, we adhere to one particular method, either by letting water enter the sand as measured dry or by pouring sand into the water; because, by varying the methods, the results obtained will be materially different.

Mr. Humphrey. Mr. HUMPHREY.—I am glad that Mr. Fuller and Mr. Taylor and others have brought out points in discussing this question of the percentage of voids, and I would like to say that I did not intend, in answering Mr. Brown's question, to stand for any method. I did not tell the whole story in describing that method. We take the sand which comes to the laboratory, dry it, determine its specific gravity, get the percentage of absorption and then dry

the sand before determining the percentage of voids, that is, before placing it in the percolator. When we determine the percentage of voids by the percolator method the absorption and the specific gravity and therefore the calculated percentage of voids to compare with the amount observed by means of the percolator. The method suggested by Mr. Fuller is that which we have in use and is the one which was adopted by the Joint Committee. After a thorough discussion of the subject the committee decided that in all determinations of this kind the percentage of voids should be also determined by calculation from the specific gravity. **Mr. Humphrey.**

MR. BROWN.—It strikes me that the amount of voids in any material used for concrete, is the amount of voids obtained in the resulting concrete and not in the dried material. **Mr. Brown.**

If there is sufficient water and pressure (from weight of materials) the aggregates will form a more dense body than in handling them in the dry state, and as the first condition is that in actual practice, I should think that a method of determining the voids recognizing this point would be best.

Has any one present made any experiments to ascertain the comparative weight of loose, packed, damp, wet and sand dried after allowing it to fall through water to a given volume? It will be found I think in all cases that the voids are reduced materially by dropping through water.

MR. TAYLOR.—It seems to me that if Mr. Humphrey already knows the specific gravity of the sand, he takes a very roundabout method of getting the voids; because if the weight of the sand in the cylinder is known, the percentage of voids follows from a little calculation, all these water percolations being entirely unnecessary. **Mr. Taylor.**

MR. FULLER.—Answering Mr. Brown as to the determination of per cent. of voids by dropping sand slowly through water, the speaker would say that this method occured to him at one time as being a possible way of obtaining a satisfactory result; but on making several hundred tests of that kind he found that very different results are obtained depending on the size of the sand grains. A great many tests were then made by separating the sand grains into different sizes, beginning with the very finest which will go through a 200 sieve, and it was found that there are variations of fully 50 per cent. in the determinations of the voids in sand by the method of dropping through water. **Mr. Fuller.**

SOME TESTS OF REINFORCED CONCRETE BEAMS.

By Gaetano Lanza.

Inasmuch as the writer believes that a prerequisite to the deduction of suitable formulæ for the determination of the strength of reinforced concrete beams, is an experimental study of the strains actually occurring in such beams, under a variety of loads, the following account will be given of certain work of this character performed under his direction in the laboratory of Applied Mechanics at the Massachusetts Institute of Technology by Messrs. W. H. Adams, I. F. Atwood, H. O. Blatt and J. D. McQuaid for their graduating theses.

The beams included in this paper were thirteen in number, all 8 by 12 in. cross-section and 11 ft. span. They were all supported at the ends, and loaded transversely, the load being applied, in each case, at two points, each 22 in. from the middle of the span.

The composition of the concrete was the same in all cases, viz: 1 part, by volume, of Portland cement (Star brand), 3 parts, by volume, of sharp, clean, and coarse sand from Newburyport, Mass., 4 parts, by volume, of trap rock from Somerville, Mass., which would pass a 1-inch ring sieve, and 2 parts, by volume, of the same kind of rock which would pass a $\frac{1}{2}$-inch ring sieve; these proportions being such as would, theoretically, a little more than fill the voids in each case. The quantity of water used, varied from 6 to $7\frac{1}{2}$ per cent. by weight.

The tensile strength of the steel reinforcing bars used, when plain, varied from 56,000 to 63,000 pounds per square inch, and, when twisted, the tensile strength was about one-third greater. The elastic limit varied from 29,000 to 38,000 pounds per square inch for the plain bars, and, for the twisted, from 52,000 to 61,000 pounds per square inch.

The average modulus of elasticity of the steel, was about 28,000,000 pounds per square inch.

The reinforcing rods which were either square bars, or square bars twisted, extending longitudinally throughout the length of the beams, the centers of their cross-sections, at the ends, being 2 inches from the bottom, with a sag of from $\frac{1}{8}$ to $\frac{3}{16}$ of an inch at the middle of the span. Beams L 23, and L 24, each contained, in addition to their reinforcing rods, a vertical layer of expanded metal, extending throughout their length and height.

The strains were measured at four points in the depth of the beam on each side. The points at which strains were measured were respectively 1 in. and 5 in. above and below the center of the depth of the beam; those 5 in. above and below the center being determined on a gauged length of 27 inches, and those 1 in. above and below the center being determined on a gauged length of 12 inches.

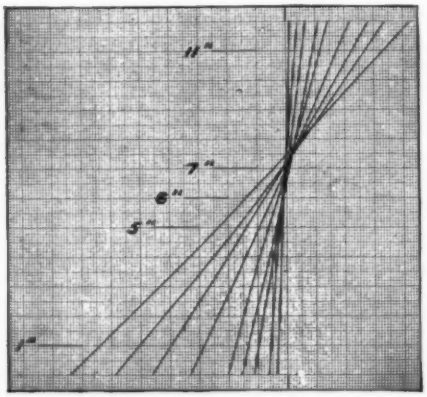
The strains plotted in the strain diagrams are those corresponding to the difference between the load indicated, and the initial load, the amount of which is shown in each case in the plots.

On the folding plate plots will be found showing, in the case of each beam, the height of the neutral axis above the bottom of the beam, as determined by experiment, compared with that which would be obtained from calculation by assuming the strains to vary directly as their distances from the neutral axis, and the stresses in the concrete and the steel, respectively, to be the product obtained by multiplying the strains by the respective moduli of elasticity of the materials. The height of the neutral axis above the bottom of the beam in each case is also given in the tables, under the heading Neutral Axis.

It will be seen that, in the beams tested, the extreme motion of the neutral axis under different loads was not very great.

In making the calculations for the positions of the so-called theoretical neutral axis, the modulus of elasticity of the steel was taken as 28,000,000 pounds per sq. in. and that of the concrete as 3,000,000 pounds per sq. in., which was approximately the average of the moduli of elasticity of the concrete used as determined by compressive tests.

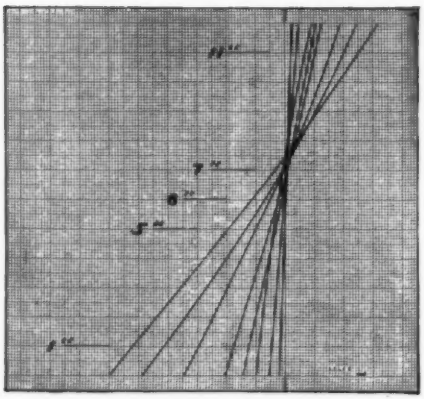
In the strain diagrams the abscissas represent the strains to a scale of 0.25 in. for 0.0001 strain, while the ordinates represent distances from the bottom of the beam.



BEAM A—1.

One 1-inch plain rod. Age, 53 days.
Initial load, 1250 lbs.
Breaking load, 15250 lbs.

Load. Pounds.	Neutral Axis. Inches.
2250	7.6
3250	7.5
4250	6.7
5250	6.6
6250	6.9
8250	7.0
10250	7.2
12250	7.2
14250	7.5

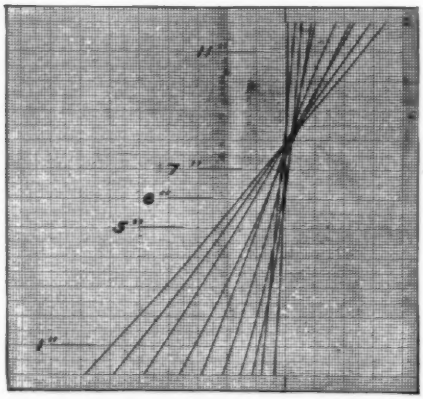


BEAM A—2.

One 1-inch twisted rod. Age, 49 days.
Initial load, 1250 lbs.
Breaking load, 16500 lbs.

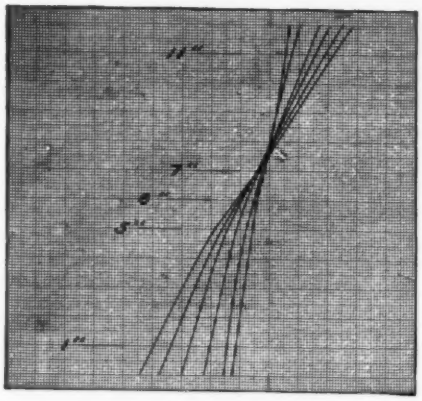
First Application.

Load. Pounds.	Neutral Axis. Inches.
2250	5.4
3250	6.2
4250	7.4
5250	6.7
6250	6.7
8250	7.0
10250	7.1
12250	7.4



Second Application.

2250	7.6
3250	8.4
4250	6.4
5250	6.5
6250	7.2
8250	7.7
10250	7.4
12250	7.9
14250	7.9
16250	7.9

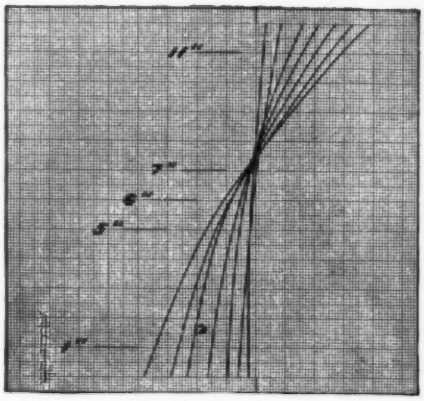


BEAM B—3.

Two ¾-inch plain rods. Age, 43 days.
Initial load, 1250 lbs.
Breaking load, 15950 lbs.

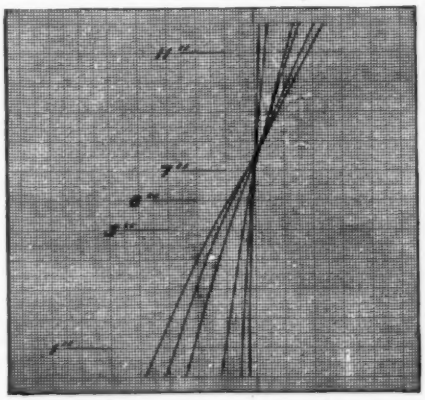
First Application.

Load. Pounds.	Neutral Axis. Inches.
2250	6.0
3250	7.1
4500	6.5
5250	6.9
6250	7.2
8250	7.5
10250	



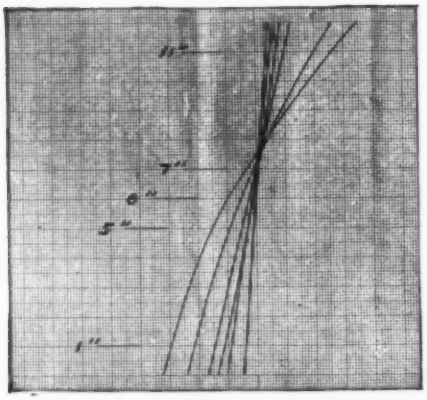
Second Application.

2250	8.0
3250	6.8
4500	7.7
6250	7.6
8250	7.6
10250	7.4
12250	7.5



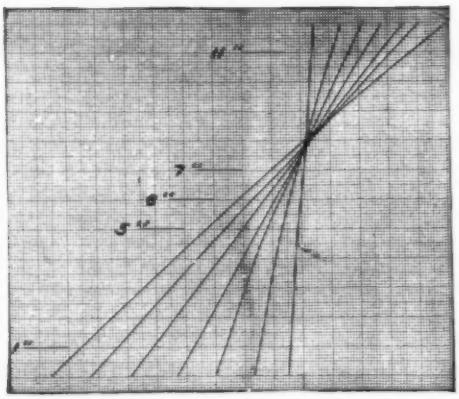
Third Application

2250	7.7
3250	7.4
5250	7.1
8250	7.4
10250	7.5
12250	7.5



Fourth Application.

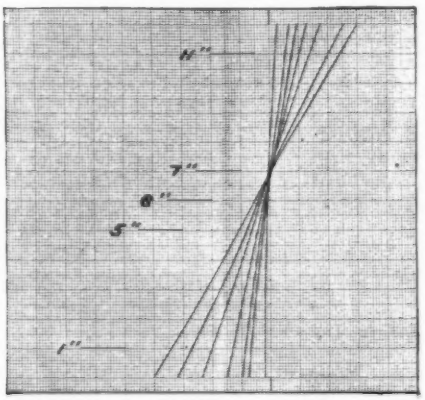
Load. Pounds.	Neutral Axis. Inches.
5250	7.8
6250	7.8
8250	7.7
10250	7.7
12250	7.6
14250	7.5



BEAM C—5.

Four $\frac{1}{2}$-inch plain rods.
Age, 35 days.
Initial load, 2000 lbs.
Breaking load, 17500 lbs.

Load. Pounds.	Neutral Axis. Inches.
4000	6.3
6000	7.4
8000	7.6
10000	7.5
12000	7.6
14000	7.7
16000	7.9

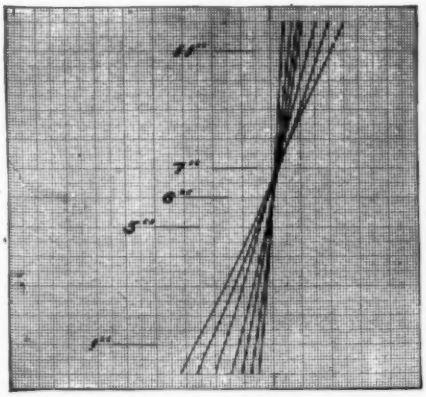


BEAM E—9.

Two $\frac{7}{8}$-inch twisted rods.
Age, 54 days.
Initial load, 1250 lbs.
Breaking load, 22250 lbs.

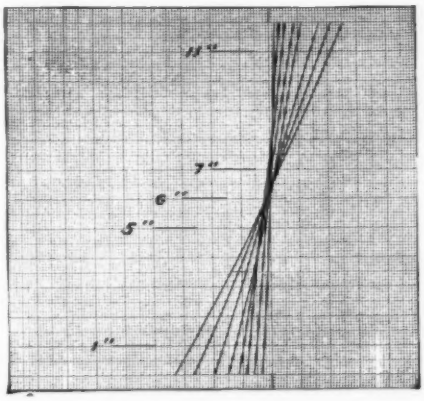
First Application.

Load. Pounds.	Neutral Axis. Inches.
2250	8.0
4250	6.9
5250	6.9
6250	6.9
8250	6.9
10250	6.9
12250	6.9



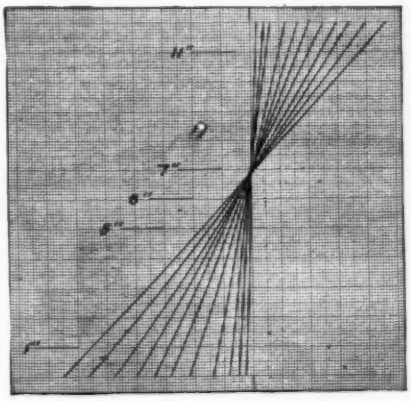
Second Application.

Loads. Pounds.	Neutral Axis. Inches.
3250	5·7
4250	5.6
5250	5·9
6250	5·9
8250	6.5
10250	6.3
12250	6 5



Third Application.

2250	6.0
3250	7·1
4250	7·5
5250	6.6
6250	6.0
8250	6.3
10250	6.3
12250	6.3

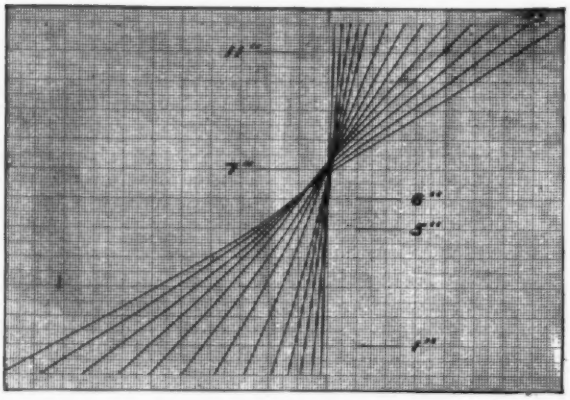


Fourth Application.

2250	6.5
3250	7.0
4250	7·1
6250	6.8
8250	6.8
10250	6.9
12250	7.0
14250	6.9
16250	6.8
18250	6 8
20250	6 9

BEAM L—23.

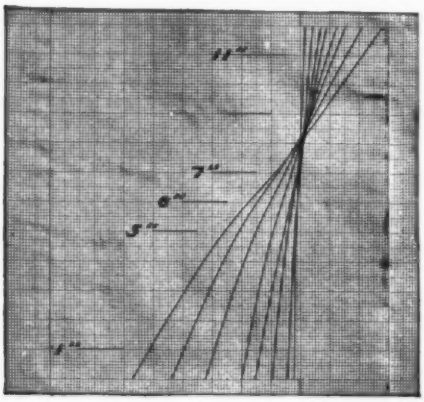
Two ¾-inch twisted rods and expanded metal. Age, 40 days.
Initial load, 1250 lbs. Breaking load, 24250 lbs.



Load. Pounds.	Neutral Axis. Inches.
2250	6.1
3250	5.8
4250	6.3
5250	6.5
6250	6.7
8250	7.1
10250	7.1
12250	7.2
14250	7.3
16250	7.3
18250	7.1
20250	6.9
22250	6.8

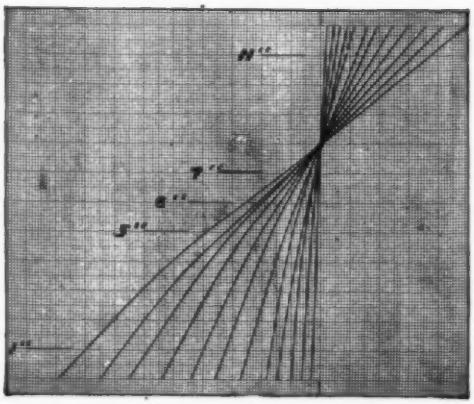
BEAM L—24.

One 1-inch twisted rod and expanded metal. Age, 49 days.
Initial load, 1250 lbs.
Breaking load, 21750 lbs.



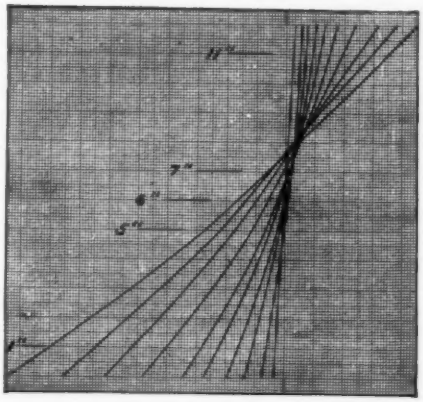
First Application.

Load. Pounds.	Neutral Axis. Inches.
2250	8.3
3250	7.4
4250	7.7
5250	7.6
6250	8.0
8250	8.2
10250	8.2
12250	8.1



Second Application.

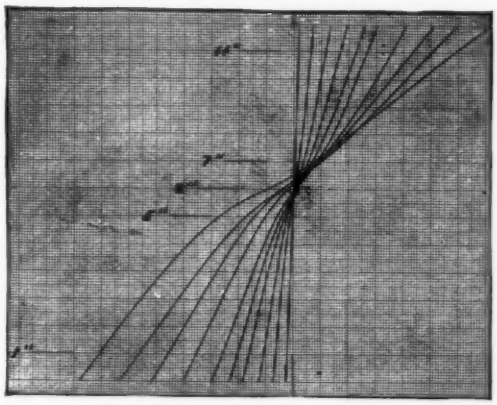
2250	7.7
3250	7.9
4250	8.0
5250	7.7
6250	8.1
8250	8.0
10250	8.1
12250	8.1
14250	8.1
16250	8.1
18250	8.0
20250	8.0



BEAM G—13.

Two 1-inch twisted rods.
Age, 14 months.
Initial load, 1300 lbs.
Breaking load, 33950 lbs.

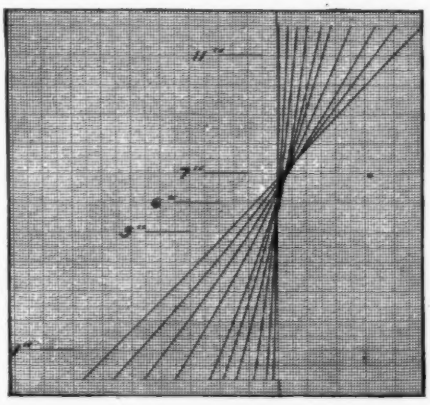
Load. Pounds.	Neutral Axis. Inches.
4300	6.2
6300	5.2
8300	5.8
10300	6.0
12300	6.5
14300	6.7
18300	7.1
22300	7.5
26300	7.7
31300	7.6



BEAM G—14.

Two 1-inch plain rods.
Age, 14 months 2 days.
Initial load, 1300 lbs.
Breaking load, 32100 lbs.

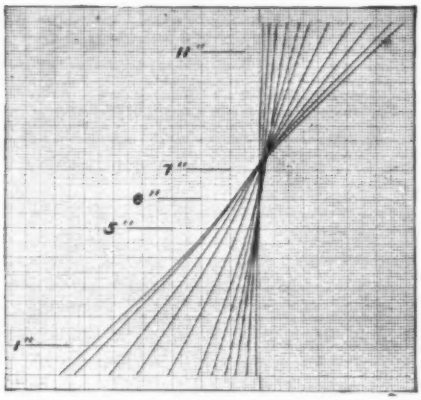
Load. Pounds.	Neutral Axis. Inches.
2300	5.5
4300	5.8
6300	5.8
8300	5.8
10300	5.8
12300	5.9
16300	6.2
20300	6.2
24300	6.2
28300	6.5



BEAM H—15.

Three $\frac{7}{8}$-inch twisted rods.
Age, 14 months 8 days.
Initial load, 1300 lbs.
Breaking load, 36600 lbs.

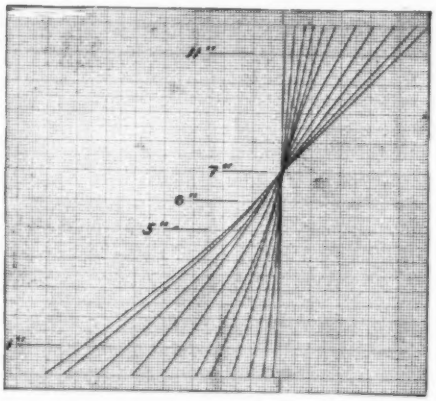
Load. Pounds.	Neutral Axis. Inches.
2300	5.9
4300	5.6
6300	6.0
8300	5.6
10300	6.0
12300	6.0
16300	6.3
20300	6.5
24300	6.6
28300	6.8



BEAM H—16.

Three $\frac{7}{8}$-inch plain rods.
Age, 14 months 7 days.
Initial load, 1300 lbs.
Breaking load, 31500 lbs.

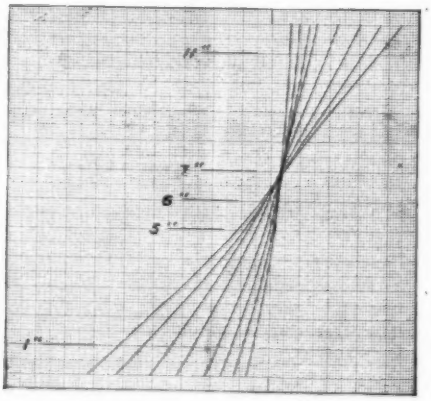
Load. Pounds.	Neutral Axis. Inches.
2300	7.1
4300	6.5
6300	6.8
8300	6.5
10300	6.8
12300	6.9
16300	7.0
20300	7.1
24300	7.0
28300	7.0
30300	7.0



BEAM I—17.

Four $\frac{3}{4}$-inch twisted rods.
Age, 14 months 2 days.
Initial load, 1300 lbs.
Breaking load, 32200 lbs.

Load. Pounds.	Neutral Axis. Inches.
2300	7.9
4300	6.5
6300	6.2
8300	5.7
10300	6.4
12300	6.5
16300	6.9
20300	7.1
24300	7.2
28300	7.2
30300	7.1



BEAM I—18.

Four $\frac{3}{4}$-inch plain rods. Age, 14 months 8 days.
Initial load, 1300 lbs.
Breaking load, 31800 lbs.

Load. Pounds.	Neutral Axis. Inches.
6300	4.
8300	4.6
10300	5.0
12300	5.6
16300	6.2
20300	6.3
24300	6.3
28300	6.4

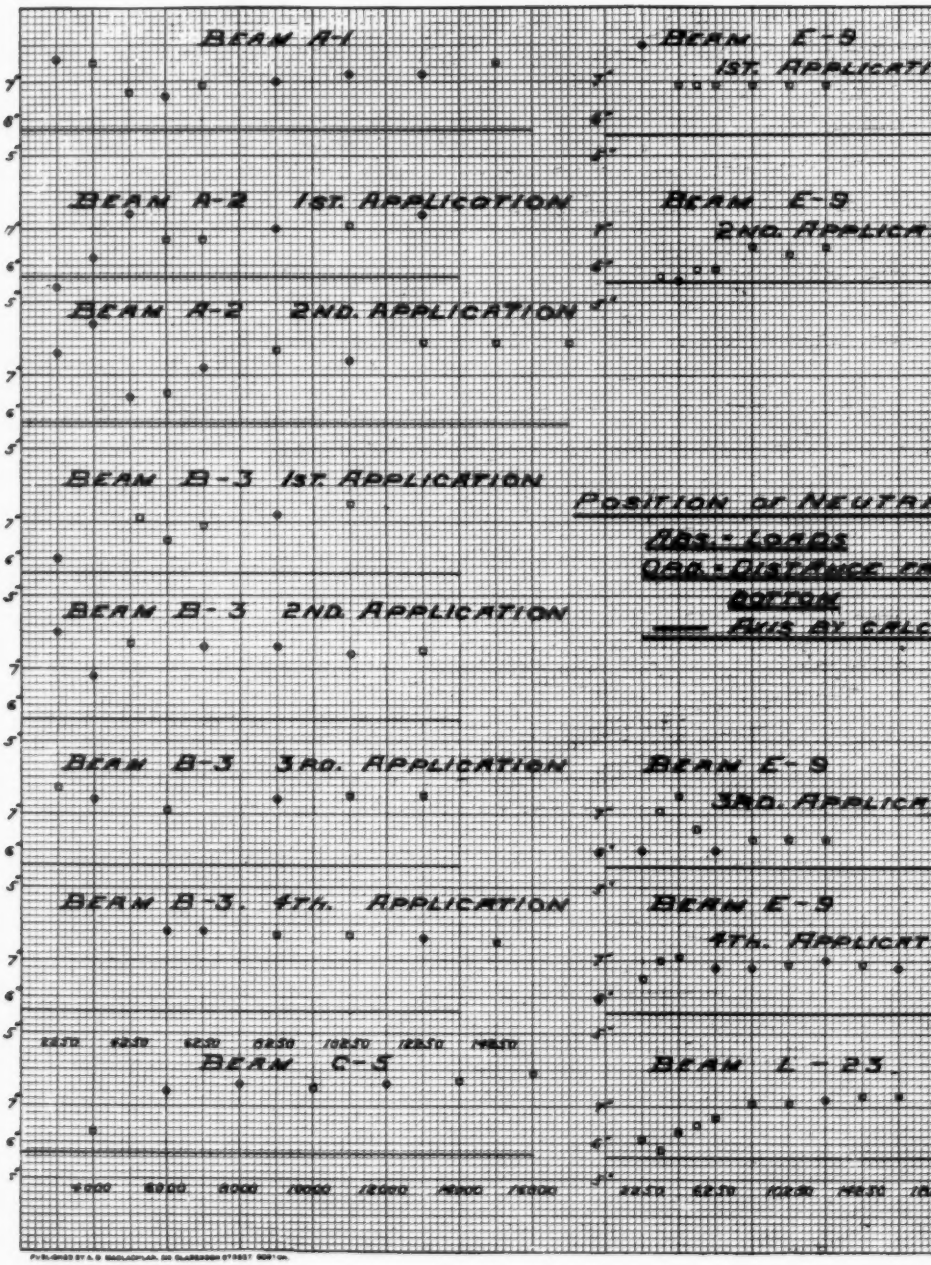
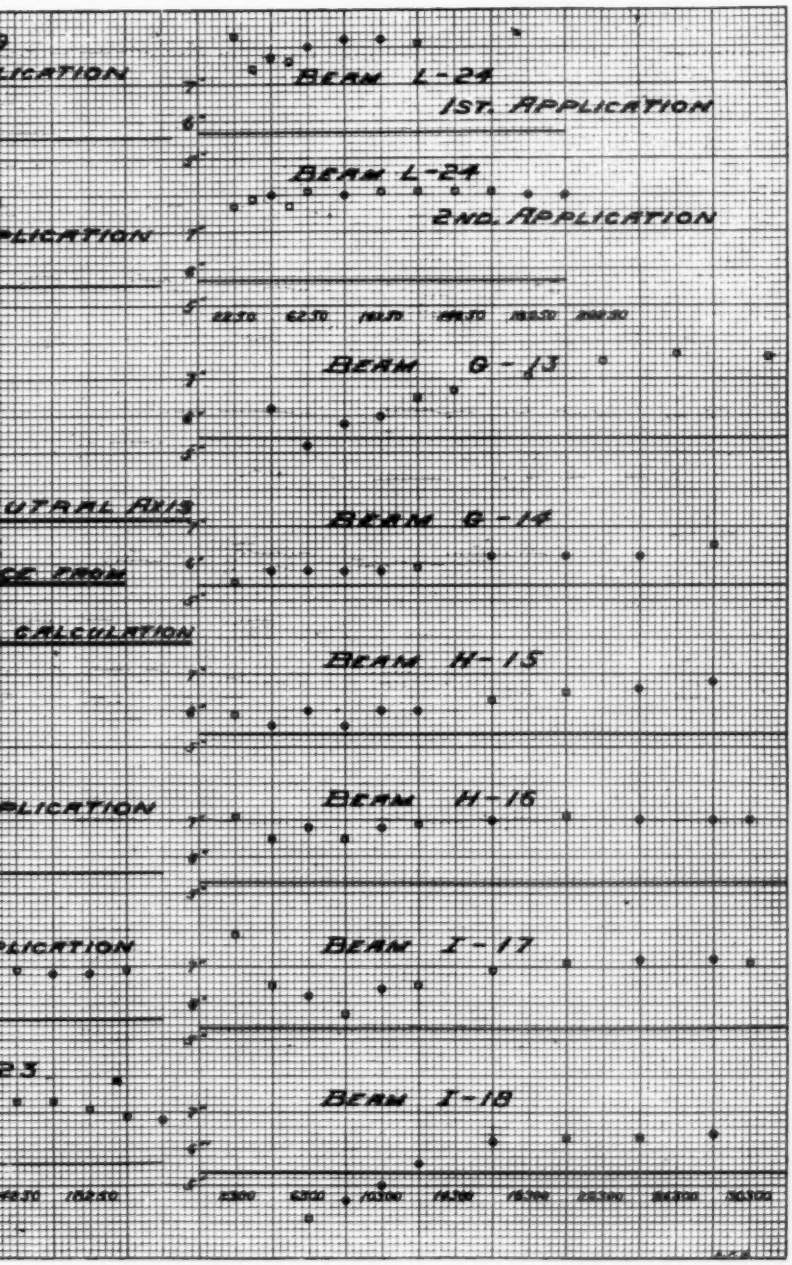

BEAM A-1
BEAM A-2 1ST. APPLICATION
BEAM A-2 2ND. APPLICATION
BEAM B-3 1ST. APPLICATION
BEAM B-3 2ND. APPLICATION
BEAM B-3 3RD. APPLICATION
BEAM B-3. 4TH. APPLICATION
BEAM C-5
BEAM E-9
1ST. APPLICATI
BEAM E-9
2ND. APPLICA
POSITION OF NEUTRA
ABS.= LOADS
DIST. = DISTANCE FR
BOTTOM
AXIS BY CALC
BEAM E-9
3RD. APPLICA
BEAM E-9
4TH. APPLICAT
BEAM L-23

PLATE XXI.
PROC. AM. SOC. TEST. MATS.
VOLUME VI.
LANZA ON TESTS OF CONCRETE BEAMS.



TESTS OF REINFORCED CONCRETE BEAMS.

By C. J. Tilden.

The tests to be described were made at the University of Michigan in April and May, 1906, for the Trussed Concrete Steel Company of Detroit.

Seven beams were tested,—four on a span of 13 feet, two on a span of 17 feet 8 inches and one on a span of 21 feet 8 inches. The four smallest beams were 12 inches wide, 16 inches deep and about 14 feet long, two of which, numbered 1 and 2, were reinforced with the Kahn trussed bar, while the remaining two, numbered 6 and 7, were reinforced with plain round rods for purposes of comparison. Beams 3 and 4 were each 16 inches wide, and 20 inches deep, and 18 feet 8 inches in length, both reinforced with Kahn bars. The largest beam, number 5, was 2 feet deep, and 20 inches wide, with a total length of 22 feet 8 inches and reinforced with Kahn bars. The span in each case was clear, and kept constant by the use of steel rollers between the supporting blocks and the under side of the beam.

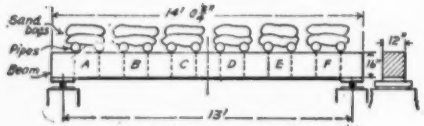
All the beams were reinforced with steel both top and bottom, that is against compression as well as tension. The tension reinforcement varied from 1.08 to 2 per cent. of the area of cross-section above center of steel, the area of steel in compression being from one-third to one-half of that in tension. The arrangement of reinforcing bars in the several beams is shown in Figs. 1 to 4, and the shapes and sizes are given in the table.

The beams were made in December, 1905, by the engineer of the Trussed Concrete Steel Company, and tested by the writer after four or five months. (The age in days at testing is given in column 4 of the accompanying schedule.) The mixture used was one part of Etna cement, two parts of clean sand and four parts of crushed limestone broken to $\frac{3}{4}$ of an inch or smaller. The forms were tight and a wet mixture used, the mixing being done by hand. The resulting concrete was very dense and uniform. To prevent freezing, the forms were enclosed in a rough shed and a stove fire kept burning for a week or ten days after filling the molds.

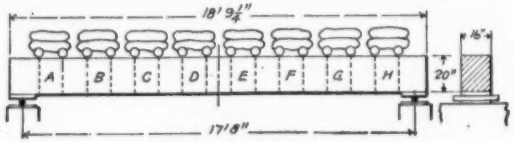
Acknowledgment is made to the *Railway and Engineering Review* for the cuts used in this paper.—Ed.

Number of Beam.	Dimensions	Nature of Reinforcement.	Age, in days, when Tested	Computed "effective" weight of beam, lbs.	Span, center to center of rollers.	Steel in Tension — At center: Area sq. in.	At center: % of bd	At reduced section: %	Steel in Compression — At Center: Area sq. in.	At Center: % of bd	At reduced section: %	Ratio of compression steel to tension	a' Top of beam to cen. of steel, ins.	a Bottom of beam to cen. of steel, inches.	d Effective depth of beam, inches.	Maximum load applied, pounds.	Nature of failure.	Total Load including weight of beam, lbs: for deflection $\frac{1}{600}$ span	causing failure	Bending Moment at center, inch pounds: for deflection $\frac{1}{600}$ span	from max. load.	Tensile stress in steel at center, pounds per sq. inch: deflection $\frac{1}{600}$ span	Max. load.	Bending moment at section of reinforced area of tension steel.	Tensile stress in steel at reduced section.
1	12"x15$\frac{3}{8}$"x14'0$\frac{3}{8}$"	Kahn bars, One ¾" top 12" cuts, " " bent 12" " Two " bottom 12" "	131	2500	13' 1.56"	2.08	1.28	1.08	0.77	.47	0.54	.37	2.0	2.2	11.6	45170	Not carried to failure.	Not determined.	47670 *	Not determined.	930000	Not determined.	38500	762000	61000
2	12"x16"x14'0$\frac{3}{8}$"	" " Two ¾" top 12" cuts, One " bottom, "	126	2500	13' 1.56"	3.41	2.00	2.46	1.54	.90	1.08	.45	1.8	1.8	12.4	73280	Compression rods buckled.	70000	75780	1365000	1478000	32300	35000	1315000	43200
3	16"x20"x18'9$\frac{1}{4}$"	" " Two ¾" top 12" cuts One " bent " Two " bottom 24" cuts	132	5500	17' 8" 2.12"	3.18	1.14	1.92	1.54	.55	1.08	.48	2.15	2.5	15.35	74850	Concrete failed, compression.	61500	80380	1630000	2128000	33400	43600	1918000	65200
4	16"x20"x18'8$\frac{3}{4}$"	" " Two ¾" top 12" cuts One " bent " Two 1¼" bottom 24" "	137	5500	17' 8" 2.12"	4.38	1.56	3.04	1.54	.54	1.08	.35	2.25	2.25	15.5	115000	Not carried to failure.	96500	120500 *	2558000	3200000	37600	47100	2880000	61390
5	20"x26"x22'8"	" " Two 1¼" top 24" cuts One 1¼" bent " Two 1¼" bottom "	151	10000	21' 8" 2.60"	4.80	1.08	3.04	2.64	.60	1.92	.55	2.4	1.8	19.8	125740	Steel failed in tension.	100000	136740	3250000	4442000	34200	46600	4130000	68500
6	12"x16"x14'0$\frac{3}{8}$"	Round rods, One 1" dia. top " Two 1" " bent " " bottom	125	2500	13' 1.56"	2.11	1.22	1.50	0.78	.45	0.78	.37	1.5	1.6	12.9	52060	Compression rods buckled.	49500	54560	965000	1063000	35400	39000	871000	45000
7	12"x16"x14'0$\frac{3}{8}$"	" " One 1" dia. top " Two ¾" " bent " " straight	128	2500	13' 1.56"	2.32	1.33	1.74	0.77	.44	0.77	.33	1.25	1.5	13.25	52230	" " "	52500	54730	1023000	1068000	33200	34700	875000	38900
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)

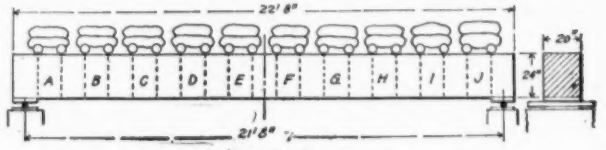
* Test not carried to failure.



Beams No. 1, 2, 6 and 7.



Beams No. 3 and 4.



Beam No. 5.

SCHEDULE.

The method of loading was designed to secure the nearest possible approach to a uniformly distributed load on the beam, and is illustrated by Figs. 1 to 5. The clear span between supports was divided into 6 or 8 or 10 bays, depending upon the span,

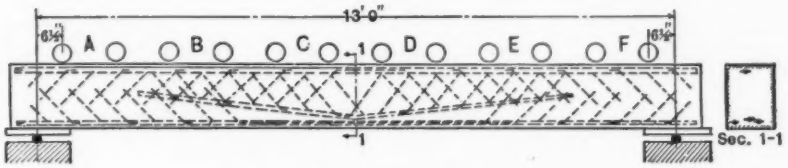


Fig. 1. Beams 1,3,4 and 5.

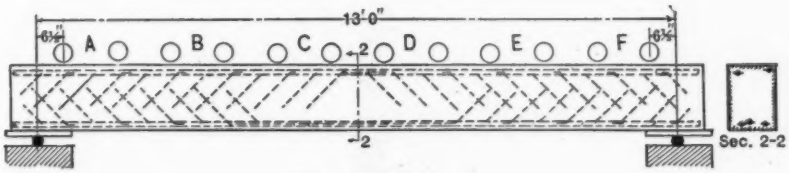


Fig. 2. Beam 2.

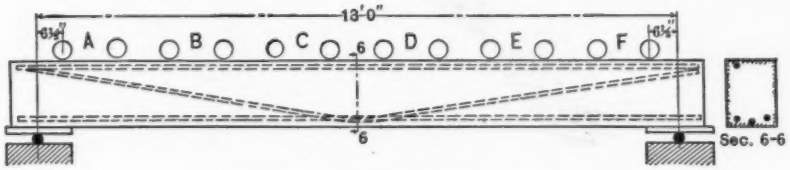


Fig. 3. Beam 6.

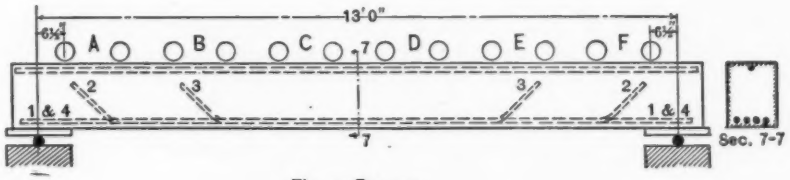


Fig. 4. Beam 7.

lettered A, B, C, etc. By means of pipes laid in pairs transversel y on top of the beam, the load was concentrated at intervals of 1 3 inches. Each pair of pipes carried a load of sand bags, each bag weighing one hundred pounds. The number of sacks on each pair of pipes was kept constant and carefully recorded as the test

progressed, so that the total load on the beam as well as the load at each point of concentration could be readily determined at any stage of the test.

The pipes rested on the beams at about their middle points, overhanging the south side of the beam about ten feet. On the north side, the ends of the pipes were carried in yokes, hung to a frame by means of spring balances (Fig. 5). These yokes were merely to prevent the load from toppling over while the sand bags were being placed, and the balances enabled that portion of the load *not* effective on the beam to be determined as a "nega-

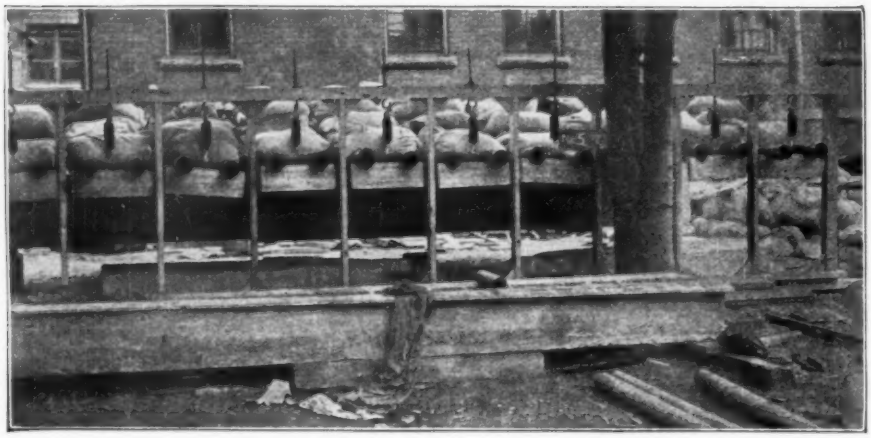


FIG. 5.

tive reading." The total load on each bay and the negative reading of the corresponding balance, was recorded at each increment of load, when the deflection was read. The absence of "arching" effect in this system of loading was evidenced in several ways at different times during the tests. In loading the beams, it sometimes happened that the load on a pair of tubes would be slightly greater on the side away from the spring balances than on the side towards them. This would cause the load on that particular pair of tubes to tilt, and this without affecting in the slightest the load on either side. Another and rather striking bit of evidence on this point occurred on sunny days about noon, when the sun's rays were parallel to the length of the pipes. The continuous

streaks of sunshine on the ground between the shadows of adjacent piles of sand bags showed conclusively the independent action of each pile.

Deflections were measured by means of a specially devised apparatus reading to one one-hundredth of an inch. The photograph, Fig. 6, shows the apparatus attached to beam No. 4, 17 feet 8 inches span. The instrument is hung on the beam at the ends, directly over the supports, by means of the frame, and the deflections read at mid-span. A block of wood, shod with brass, is rigidly attached to the beam and bears on the brass disc, which

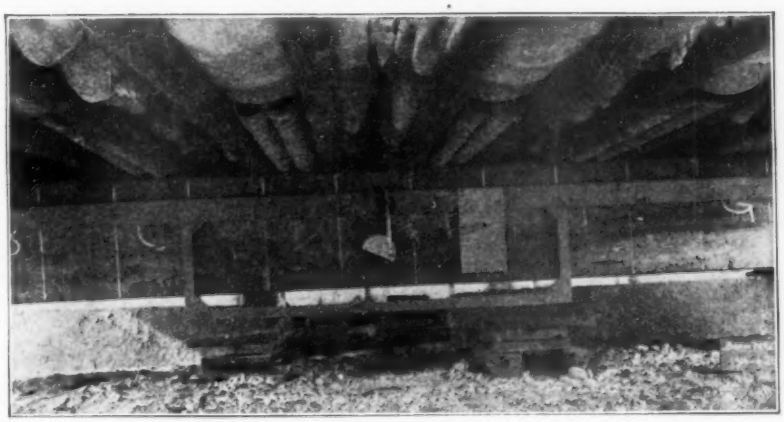


FIG. 6.

is eccentrically supported and carries a long arm, or pointer. The deflection of the beam causes an equal deflection of the center of the disc, and this causes a rise ten times as much at the end of the pointer. The scale is divided into tenths of an inch, so that deflections of hundredths are read directly.

The load deflection curves for beams 2, 6 and 7 are shown in Fig. 7, and for beams 3 and 4 in Fig. 8. These are interesting on account of the practically uniform deflection for a given increment of load up to a deflection of about one four-hundredth of the span. The curve is seen to be very closely a straight line up to this point for all the beams, and the same phenomenon was noted in the case of Beam 5, whose load deflection curve,—not shown here,— was similar to that of Beam 3. While the impossibility of

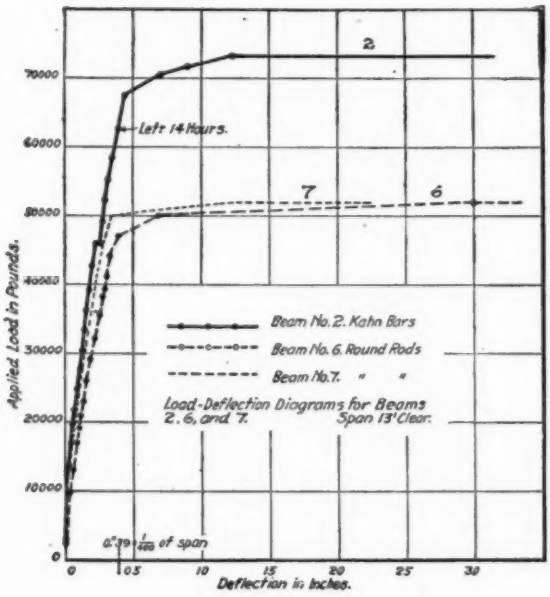

2
Left 14 Hours.
7
6
Beam No. 2. Kahn Bars
Beam No. 6. Round Rods
Beam No. 7. " "
Load-Deflection Diagrams for Beams 2, 6, and 7. Span 13' Clear.
Applied Load in Pounds.
Deflection in Inches.

FIG. 7.

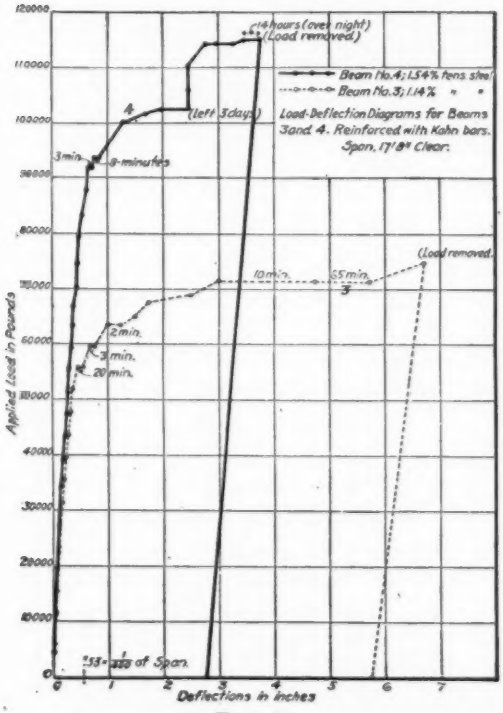
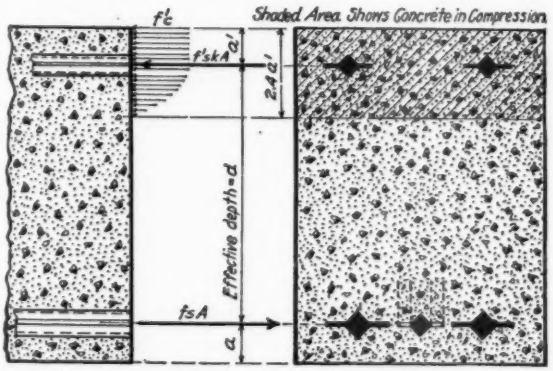

14 hours (over night) (Load removed)
Beam No. 4; 1.54% tens. steel
Beam No. 3; 1.14% " "
Load-Deflection Diagrams for Beams 3 and 4. Reinforced with Kahn bars. Span, 17' 8" Clear.
4
(left 3 days)
3 min.
8 minutes
10 min.
55 min.
(Load removed)
2 min.
3 min.
20 min.
Applied Load in Pounds
Deflections in Inches

FIG. 8.

getting close to the side of the beam during the loading precluded accurate observation of the early cracking of the concrete, the stage at which the first cracks were noted was but little more than half way up the straight portion of the curve, and it is probable that minute cracks existed much earlier. The same fact was noted in regard to the other beams, with the exception of No. 1, for which no observations were made.

The accompanying schedule gives the principal facts concerning each beam, the experimental results obtained, and some computations in regard to the probable tensile stress in the steel.



Longitudinal and transverse sections of beam No. 2 at center, showing assumed distribution of stresses.

FIG. 9.

The method of computing these stresses is explained by reference to Fig. 9, which shows longitudinal and transverse sections of Beam No. 2 at center, indicating assumed distribution of stresses. The center of steel in compression is assumed to be the center of compressive stresses on the cross-section, and the following notation is used:

A = area of steel in tension.

kA = area of steel in compression.

f_c' = maximum unit compressive stress in concrete.

f_s' = unit compressive stress in steel.

f_s = unit tensile stress in steel.

d = distance ctr. of steel in tension to ctr. of steel in compression, = effective depth of beam.

Then, Moment of Resistance $= f_s Ad$, or $f_s = \frac{M}{Ad}$ = unit tensile stress in the steel.

This rather arbitrary assumption in regard to the distribution of stress on the cross-section of the beam was made in an endeavor to fit the theory to observed facts. During the progress of the tests many photographs were taken, showing the cracks in the sides of the beams. In a subsequent detailed study of these photographs it was possible to trace the cracks, even for loads considerably below the ultimate, up to points far above the theoretical location of the neutral axis, as deduced for a beam reinforced in both tension and compression. The assumption shown in Fig. 9 as to the variation of compressive stress in the concrete, that is, a rectangle superimposed upon a parabola, brings the neutral axis 2.4 a′ below the top of the beam, and is thought to represent fairly well the actual observed conditions.

The stresses in columns 23, 24 and 26 of the schedule are all computed on this assumption. While it is a simple matter to compute the tensile stress in the steel, it is much more difficult to get any values for the compressive stresses in steel and concrete, as this depends on the ratio assumed for the moduli of elasticity of the two materials. As the value of the modulus for concrete is uncertain anyway, and varies in the same concrete with variations in stress, the compressive stresses cannot be determined as certainly as the tensile stresses, and they are not, therefore, included in the table.

INVESTIGATION OF THE THERMAL CONDUCTIVITY OF CONCRETE AND THE EFFECT OF HEAT UPON ITS STRENGTH AND ELASTIC PROPERTIES.

By Ira H. Woolson.

This paper is a record of some experiments made in continuation of work described in a paper presented to the Society last year (Vol. V, p. 335), under the title of "Investigation of the Effect of Heat upon the Crushing Strength and Elastic Propertier of Concrete." Those familiar with that paper will remember that it recorded a series of tests, showing that both the strength and elasticity of concrete were rapidly diminished by the application of comparatively low heat for moderate periods of time. The results appeared quite contradictory to well-established evidence regarding the behavior of that material in actual fires, and in fire tests of full size floor units. Endeavoring to elucidate this discrepancy, the writer made a single experiment on the conductivity of concrete which apparently explained the whole variation, and pointed to the fact that the virtue of concrete as a fire resisting material was due to its high non-conductivity. The other tests showed that if it were thoroughly heated to 1,500° F. its strength and elasticity were largely dissipated.

In the discussion which followed the reading of the paper, it was suggested that further investigation of the conductivity of concrete should be made; also, that additional proof of the other results, using larger specimens and different concrete mixtures, was desirable.

At the request of the "Joint Committee on Concrete" the writer has continued the experiments, and this paper is a summary of the new data.

The actual work of preparing and testing the specimens, making the calculations, and plotting the curves was done by students in the Department of Mechanical Engineering, Columbia University, under the writer's direction. This year the investigation was made by Messrs. R. M. Olyphant, Jr., Geo. W. Riddle,

Acknowledgment is made to the *Engineering Record* for the cuts used in this paper.—Ed.

and W. Putnam, students in the senior class, who did the work as a thesis problem. Their hearty co-operation and faithful attention to detail has alone made this paper possible.

The aggregate used was the same as last year, namely, a 1-2-4 mixture of Portland cement, sharp sand and ¾-inch clean, broken stone, both trap rock and limestone being employed. In addition to these, other specimens were made in the same proportions, using clean ½ inch quartz gravel instead of the broken stone, and in another set, clean boiler cinders instead of stone.

The cement was furnished by the Committee and was said to be composed of a mixture of "Giant," "Lehigh" and "Vulcanite." It was a slow-setting cement, taking 7 hours 40 minutes for initial set, and 14 hours 10 minutes for hard set. The average strength neat for 1 day was 246 pounds; 7 days was 710 pounds. Mixed with three parts sand, the average for 7 days was 160 pounds, and for 28 days, 286 pounds.

The concrete was mixed moderately wet and well tamped. The specimens were left in the molds 36 hours, then removed and submerged in water for 7 days, after which they were allowed to stand for 7 weeks in a cellar being occasionally sprinkled.

It was suggested that instead of raising the temperature of the specimens very slowly, so that three or four hours were consumed in attaining a furnace temperature of 1,500 to 2,000° F., as was done last year, it would be instructive to bring the furnace temperature rapidly up to some fixed point, then holding it there for a definite period. The idea being that duplicate tests would be easier and the conditions approach more nearly those of an actual fire. This was done in all cases in the present series of experiments; 1,500° F. was adopted as a fair average, and the furnace raised to that temperature in 40 to 60 minutes and held there for the balance of the test. It was thought unwise to raise the temperature faster than this for fear of producing internal stresses that might rupture the specimens. In one instance the furnace did not work properly and the necessary heat was not secured in an hour. Three sizes of specimens were made—4-inch cubes, 7-inch cubes and 6 in. x 6 in. x 14 in. prisms. The latter were used for measuring the elastic properties. The 4-inch cubes were made for comparing the strength of the new concrete with that of last year.

Method of Heating.—The specimens were heated in an oven

type of gas furnace. Those placed entirely inside the furnace were protected from the direct impact of the flames on the sides by shields of fire brick or clay tiles. This was done to insure as nearly as possible an even distribution of heat throughout the whole specimen.

Three and five hours were chosen for the times of heating the large specimens, and two and three hours for the 4-inch cubes. It was estimated that the internal temperature of the small specimens in that time would be about the same as that of the large specimens exposed the longer time. These time periods include that required for the furnace to reach 1,500 degrees. After heating, the specimens were removed from the furnace and allowed to cool slowly in air.

The temperatures were measured by a carefully standardized Le Chatelier pyrometer, readings being taken simultaneously every ten minutes upon the thermo-couple placed between the specimens, which registered the temperature of the furnace, and upon those embedded in the specimens which gave the corresponding internal temperatures at the points taken.

The specimens used to measure the conductivity by heating upon one side only, were placed in the doorway of the furnace with the exposed face on a line with the furnace wall. These specimens completely filled the doorway with the exception of an inch at the top which was filled with magnesite board. Fig. 1 is a sketch showing arrangement of large specimens in the furnace and in doorway.

Specimens designed for strength tests were faced with plaster-of-Paris before testing.

A few tests were made upon some specimens left over from last year's experiments, and two or three upon some samples of 1-2-3 trap rock mixtures two years old.

CLASSIFICATION OF SPECIMENS.

Lot A.....	1–2–4	mixture,	limestone, age 2 months.
" B.....	"	"	trap rock, age 2 months.
" C.....	"	"	cinder, age 2 months.
" D.....	"	"	gravel, age 2 months.
" E.....	"	"	limestone, age 1 year
" F.....	"	"	trap rock, age 1 year.
" H.....	"	"	trap rock, age 1 year.
" K.....	"	"	trap rock, age 2 years.

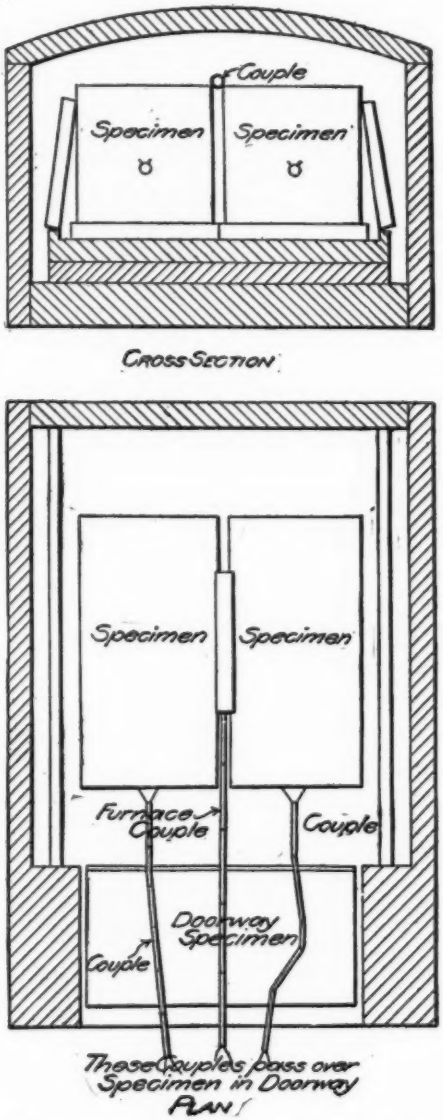


FIG. 1.—Arrangement of Specimens in Furnace and Doorway.

Conductivity Tests.—Most of the specimens used in this investigation were 7 in. cubes, this being as large as the furnace would take. A few were 6 in. x 6 in. x 14 in. prisms. When these specimens were made thermo-couples were cast in them at varying distances from the surface, the idea being that when these were tested in the furnace and temperature readings taken simultaneously upon the furnace atmosphere, and the couples embedded at varying depths in the concrete, the rate of transmission of heat through the concrete would be obtained. The work was carefully

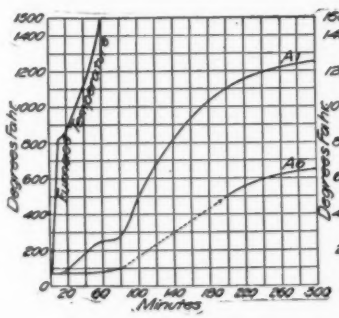


FIG. 2.—Limestone.

A–1. In Furnace. Couple 3 in. from Face.
A–6. In Doorway. Couple 4½ in. from face.

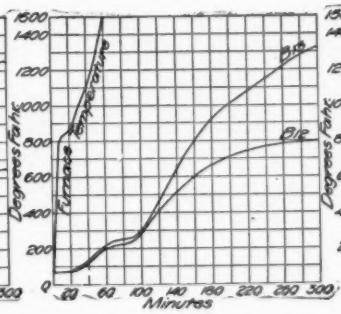


FIG. 3.—Trap.

B–13. In Furnace. Couple 1 in. from Face.
B–12. In Doorway. Couple 1½ in. from Face.

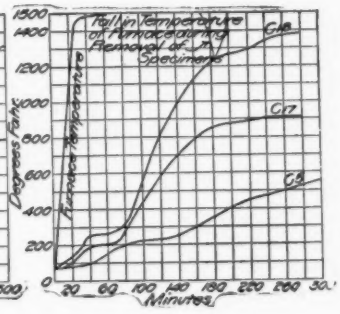


FIG. 4.—Cinder.

C–18. In Furnace. Couple 2 in. from Face.
C–17. In Furnace. Couple 3 in. from Face.
C–5. In Doorway. Couple 1½ in. from Face.

done but results were confusing, and subsequent breaking of the specimens showed that the couples had been shifted by tamping the concrete when the specimens were made. In some cases they were an inch out of place and this completely nullified the work in regard to obtaining a rate of transmission from these specimens. Figs. 2 to 5 are the curves plotted from these tests for a period of five hours in each instance. One curve gives the temperature of the furnace, which was brought up to 1,500° F. in less than an hour and held there for the balance of the test, and the other curves show the corresponding temperatures on the interior of the specimens. Although the depths given to the couples are not entirely reliable for reasons already explained, nevertheless the

curves are very interesting in showing the general lag in the rise of temperature in the specimen as compared with the furnace temperature.

The gravel specimens were the only ones which attained an interior temperature equal to the furnace temperature.

It is rather surprising to note that cinder came next to the gravel in the amount of interior heat recorded, for cinder concrete is well known to be an effective fire resistant. However, the cinder concrete specimen, tested in the furnace doorway, gave the lowest interior heat. It was found impossible with the small

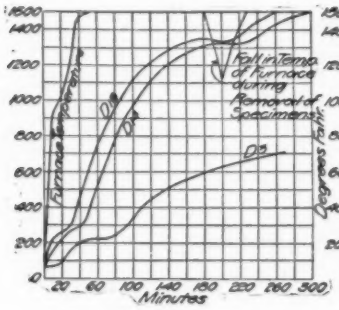


FIG. 5.—Gravel.
D–13. In Furnace. Couple 2 in. from Face.
D–14. In Furnace. Couple 3 in. from Face.
D–3. In Doorway. Couple 4½ in. from Face.

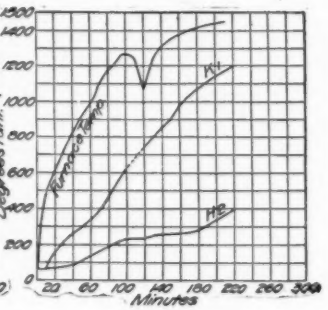


FIG. 6.—Trap.
K–1. In Furnace. Couple 1½ in. from Face.
H–2. In Doorway. Couple 4½ in from Face.

furnace employed to maintain an even distribution of heat, and undoubtedly some of the conflicting testimony of the tests was attributable to this cause.

The curves in Fig. 6 are from tests of specimens one and two years old, and although the furnace worked badly, thus giving a very slow temperature rise, there is no evidence that either specimen possessed heat resisting-qualities superior to those of the new concretes.

Attention is called to one peculiar characteristic in all the curves. This is the flattening out at or a little after the 212 degree

point is past, showing that after steam begins to generate there is little if any rise in temperature until all the water in the concrete has been evaporated. The only curve in which this peculiarity is absent is "K," Fig. 6, and this specimen was two years old; it had been kept in a very dry room for over a year, and probably contained very little moisture. This was the only specimen available at this age, and unfortunately it was tested when the furnace worked badly so the results are not conclusive.

After ascertaining that the location of the thermo-couples in the above described specimens were not all exact, one special

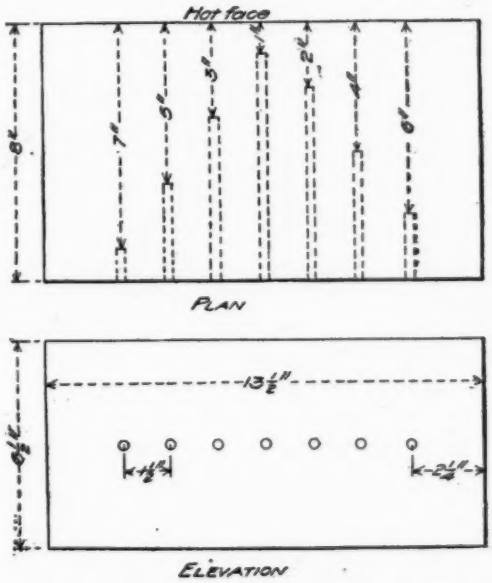


FIG. 7.--Special Transmission Specimen.

trap rock block was made having seven holes $\frac{1}{4}$ inch in diameter, cored in as shown in Fig. 7. The bottom of the holes was arranged from one to seven inches from the face to be exposed to heat, and the holes were spaced $1\frac{1}{2}$ inches apart. Thermo-couples were sealed in these holes and all connected through a switch-board to the same galvanometer. The position of these thermo-couples was absolutely assured.

This specimen was placed in the furnace doorway and sub-

jected to 1,500° F. on one face for five hours. (See Fig. 8.) Readings were taken every ten minutes on each thermo-couple, and the results are shown in the plotted temperature curves in Fig. 9. These curves are very instructive although there is some inter-

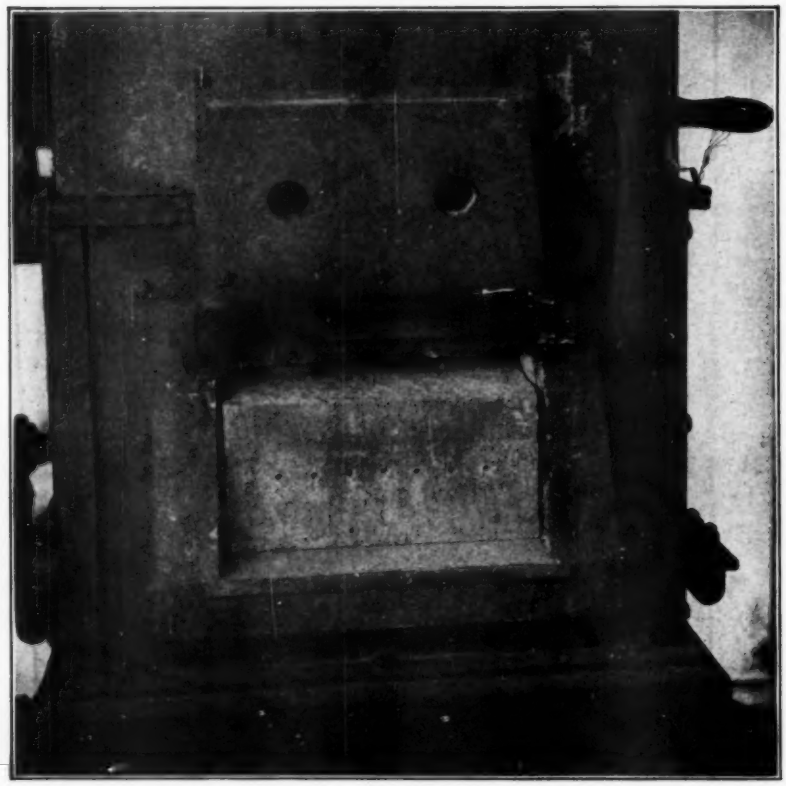


FIG. 8.—Specimen in furnace door after test, and after removal of packing around edges. Holes in specimen show location of thermo-couples.

ference. The first salient characteristic of them all is the lag at the 212 degree point. It will be noted that this is greater with increased thickness of the concrete; also that up to three inches thickness the recorded temperature at which it occurs is above 212 degrees, showing that the surface of the concrete heated very

rapidly and went above the boiling point of water. It is undoubtedly these conditions which cause steam to generate rapidly enough to become explosive and burst off patches of concrete, which is a common occurrence in fire tests.

The curves for the points 1 and 2 inches from the heated face are nearly the same. The indications are that they would have run together, had the test continued longer. The reason for this is not apparent, but it may have been due to an accidental arrangement of the stone in the concrete in such a way

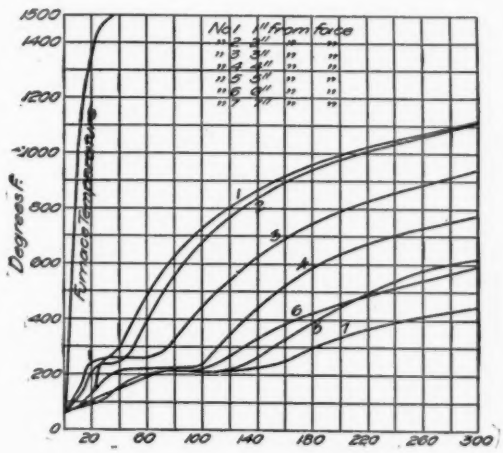


FIG. 9.—Temperature Curves for Special Specimen.

as to form a comparatively solid stone connection between the thermo-couples, which by its better conducting qualities tended to equalize the temperature between the points.

Considering these two curves as one, there is a marked parallelism between it and the curves embedded 3, 4 and 5 inches in the concrete, and the distance between them is very constant. The curves for 6- and 7-inch points are irregular, although No. 7 is nearly parallel with the others. No. 6 is particularly freakish. The reason for this is plain. Points Nos. 6 and 7 were 2¼ inches from the end of the block (see Fig. 7) and as these ends were more or less heated from the furnace walls, the points in question received some heat from this source as well as the face. This

threw their temperature curves out of harmony with the central points, which were not so affected.

As a whole, they are regular and indicate that the heat resisting quality is not a direct function of the distance from the heated surface to the interior point at which temperatures were measured. It will be noted that the curves flatten out and that doubling the distance more than doubled the time required to secure the same temperature rise.

These curves as well as those of Figs. 2 and 6 show conclusively that the very low conductivity of concrete indicated by the single test reported in our paper of last year was entirely correct. They prove that two or three inches of concrete properly mixed, tamped and set, will resist a fierce conflagration for hours without permitting a serious temperature rise upon the opposite side.

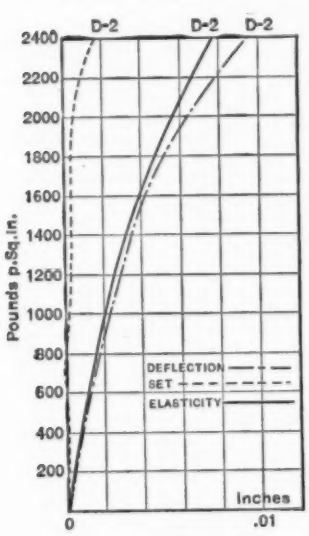


FIG. 10.—Gravel. D–2. Not Heated.

Strength and Elasticity Tests.—Table I gives the results of the tests upon the 4-inch cubes. In the year old specimens (E and F) comparison is given with tests of duplicates made when they were one month old. The increase in strength is not large. Both the limestone and trap specimens made this year are much stronger than those made a year ago. The probable explanation is that the specimens were soaked in water this year for one week on removal from the molds, and last year were only sprinkled. It is doubtful if they then received sufficient water to produce a perfect set of the cement.

It will be noted that specimens "A and B" when heated three hours at 1,500° F. were stronger than those heated two hours. This is contrary to all our previous experience and must be attributed to one of two causes; either the specimens heated two hours happened to be weak structurally, or the three hour specimens were protected in some way in the furnace and did not get the heat

credited to them. In any event the results are anomalous and should be rejected.

No strength tests were made upon heated gravel specimens because they all either fell in pieces upon removal from the furnace or were so badly cracked as to prohibit testing them.

Table II gives the modulus of elasticity (E) calculated on

TABLE I.—STRENGTH TESTS.

Lot.	Material.	Breaking Loads, lb. per sq. in.				
		Not heated.	Same lot in 1905, when 1 mo. old.	After heating 2 hrs. at 1500° F.	After heating 3 hrs. at 1500° F.	After heating 5 hrs. at 1500° F
		4 in. x 4 in. x 4 in. Specimens.				
A	Limestone.....	3030	..	980	1445	
B	Trap rock.....	3195	..	1300	1410	
C	Cinder	1360	..	750	447	
D	Gravel.....	2740	..	..	..	
E	Limestone one year old.....	1741	1968	1235	937	
		2165	1843	1110	906	
		..	1640	1200	..	
		..	..	1290	..	
F	Trap rock one year old.....	2230	1903	1525	665	
		2800	1913	..	695	
		2240	1892	..	..	4 hours.
K	6 cube limestone 2 years old.....	2290	..	..	..	2005
		6 in. x 6 in. x 14 in. Specimens.				
A	.....	2740	..	..	1345	870
B	.....	3140	..	..	1400	997
C	.....	1400	..	..	547	504
D	.....	2780	..	..	..	..

NOTE.—Where more than one breaking load is given it indicates that several specimens were tested.

increasing loads for specimens that had been heated for different times.

Usually the moduli of unheated specimens decreases with increase of load, but it is not infrequent that they reverse the rule. The exception is in evidence in this series.

The moduli of the heated specimens are very low in value, but in all cases the value increases with increase of load. This peculiarity was referred to last year. The reason is not clear, but perhaps it is because the specimen expanded on heating, and

when cooling, the outside contracts most rapidly, thus developing many fine cracks which do not entirely close when normal tem-

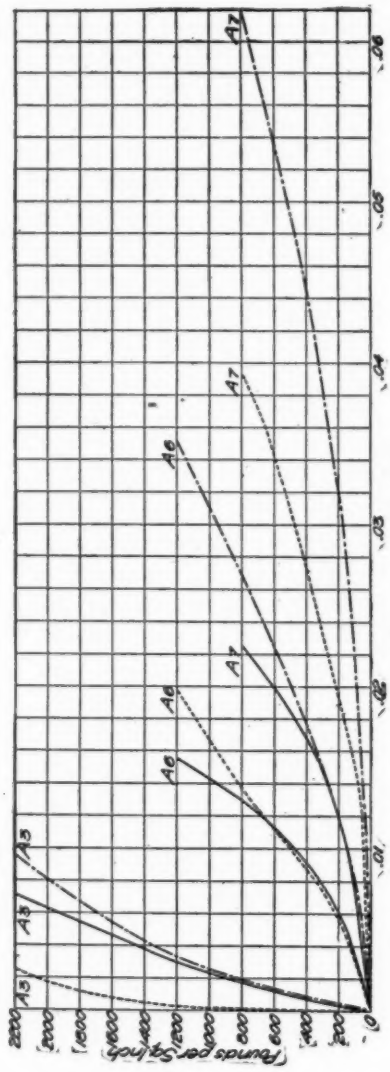


FIG. 11.—Limestone.

A–3. Not Heated. Deflection ——·——·——·——
A–7. In Furnace, 3 hours. Set ----------
A–6. In Doorway, 3 hours. Elasticity ——————

perature is reached. The first loads applied to the specimen serve merely to close these cracks and the compression observed is not, therefore, the true deformation of the concrete for these pressures.

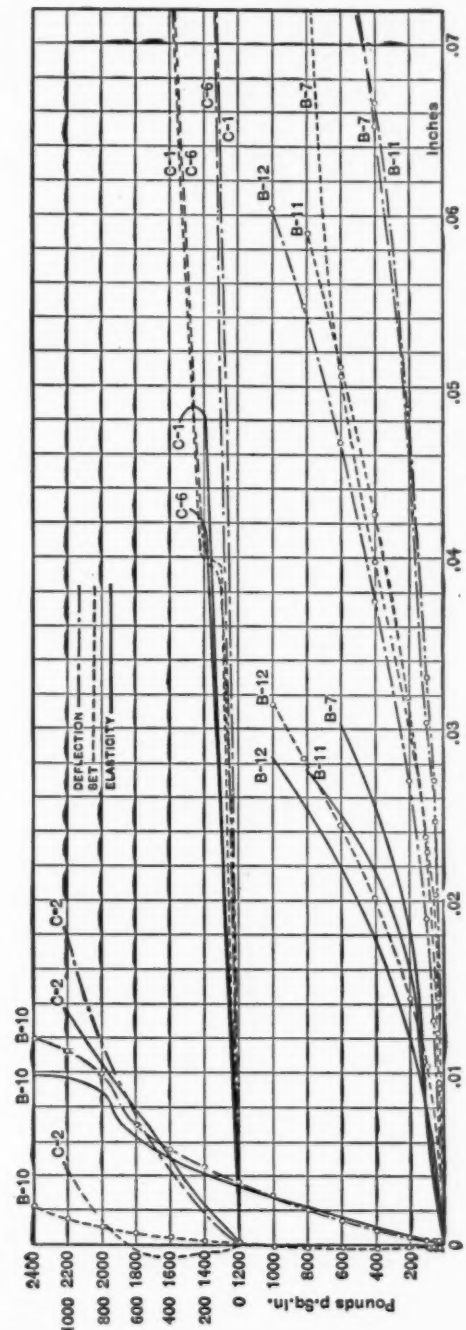


FIG. 12.—Trap. B- 7. Heated 5 hours. Cinder, C–2. Not Heated.
B–10. Not Heated. C–1. Heated 3 hours.
B–11. Heated 3 hours. C–6. Heated 3 hours.
B–12. Heated in Doorway 5 hours.

The value of the moduli decreases very rapidly with increase of heat treatment. This fact was also brought out last year, the present figures are merely confirmatory.

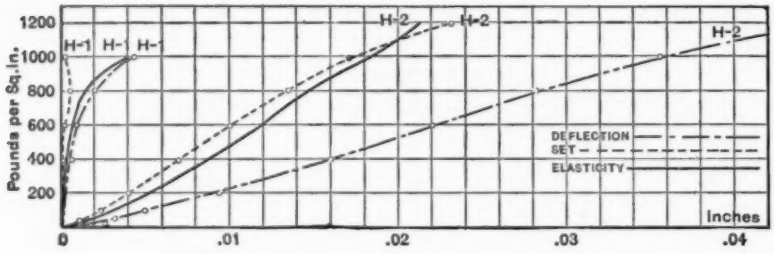


FIG. 13.—Trap. H–1. Not Heated.
H–2. Heated 4 hours.

TABLE II.—ELASTIC PPOPERTIES OF 6 IN. X 6 IN. X 14 IN. PRISMS.

Lot.	Material.	E at 200 lbs. per sq. in.			E at 400 lbs. per sq. in.			E at 800 lbs. per sq. in.	
		Unheated.	Heated 3 hrs.	Heated 5 hrs.	Unheated.	Heated 2 hrs.	Heated 5 h.s.	Unheated.	Heated 3 hrs.
A	Limestone.	6000000	200000	..	6000000	285000	..	5647000	425000
B	Trap rock..	3430000	150000	129000	4355000	222000	188000	4355000	348000
C	Cinder	1090000	49500	57100	960000	..	..	915000	..
D	Gravel	8000000	..	..	6887000	..	..	6000000	..

Blank spaces indicate that specimens had failed by fire or crushing.

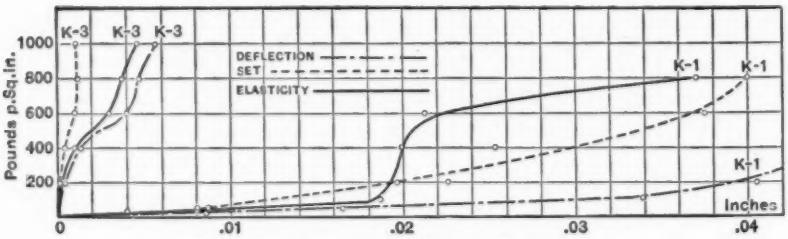


FIG. 14.—Trap. K–1. Heated 4 hours.
K–3. Not Heated.

The limestone lost about 50 per cent. of its strength when heated two hours, and the trap about 55 per cent. The difference

was undoubtedly accidental, for we well know that trap is superior to limestone in resisting heat. They both lost 68 per cent of their strength in five hours, when heated on all sides with no radiation permissible.

The strength of the 6 in. x 6 in. x 14 in. specimens heated

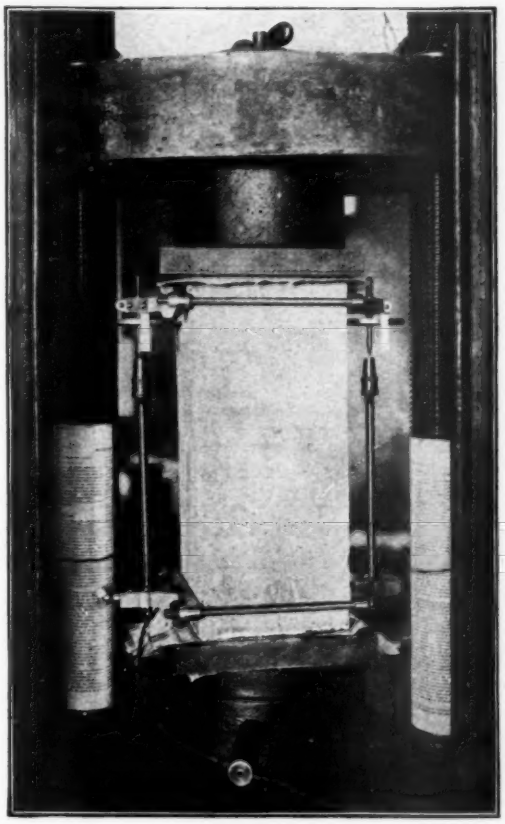


FIG. 15.

on one face, see Table III, is in marked contrast to those heated on all sides, and shows that under that condition the concrete retains a large part of its strength, even after five hours of exposure to a temperature of 1,500° F. As a matter of fact, the specimens tested in this manner really received considerable heat

upon four other faces, for it was impossible to protect them from the radiant heat from the furnace walls, so they were probably heated more thoroughly than they would have been had they formed a part of a concrete wall facing the fire.

Figs. 10 to 14 give the elastic curves of various 6 in. x 6 in. x 14 in. specimens, both before and after heat treatment. Fig. 15 shows method of measuring the deformations. Three curves are plotted for each test, (1) total deflection, (2) set, (3) true elastic; the last being obtained by subtracting the second from the first.

Negative sets are again in evidence though not so pronounced as in some previous tests. The prominent feature of the curves

TABLE III.—ELASTIC PROPERTIES OF 6 IN. X 6 IN. X 14 IN. PRISMS. HEATED ON ONE FACE ONLY.

Lot.	Material	Modules of Rupture (E) after heating 5 hours.			Breaking Load, lbs. per sq. in.
		At 200 lbs. per sq. in.	At 400 lbs. per sq. in.	At 800 lbs. per sq. in.	
A	Limestone	293,400	521,700	730,700	1,840
B	Trap rock	200,000	268,000	379,000	1,705

is the great increase in deformation with loss of strength due to heat treatment.

Fig. 16 gives the elastic curves, grouped according to treatment, without regard to the total deflections from which they were derived.

Figs. 13 and 14 are curves of specimens which were one and two years old respectively. Owing to a breakdown of the furnace these specimens were heated only four hours. It is not apparent that there was any material increase in their resisting qualities.

The marked difference in the strength of the specimens made last year and this year, in which the same stone was used, and presumably an equal quality of cement, shows that the treatment during the period of setting has much to do with the quality of the concrete. It would be interesting to ascertain if the fire resisting properties are influenced by the amount of moisture absorbed during setting.

It is fully recognized that definite conclusions cannot be drawn from tests so incomplete as these; but they serve to point

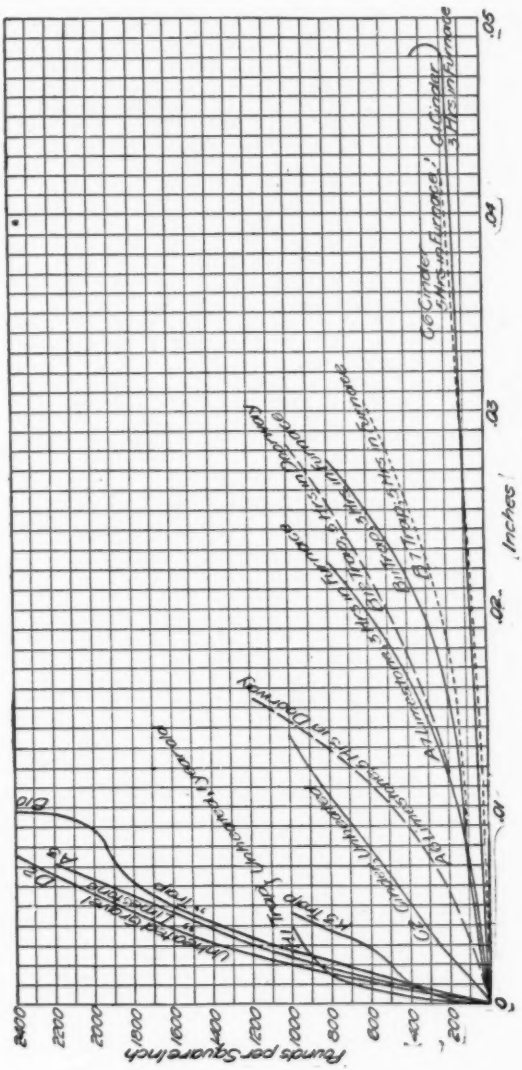


FIG. 16.—Elastic Curves of Specimens.

the way and it is hoped that more elaborate experiments may be made which will furnish the additional evidence necessary.

DISCUSSION.

Mr. Humphrey.

MR. RICHARD L. HUMPHREY.—I think the paper of Professor Woolson will be of considerable value in throwing light on a very important subject. Of course, we cannot hope to solve any of these problems in a single series of tests. The chief value of Professor Woolson's tests is, I think, to show that concrete is useful as an insulating material. The question to be determined now is what thickness is necessary in order to afford perfect insulation to the embedded metal used in the structural parts of a building. It seems fairly evident that cubes placed in a furnace in which they are exposed to heat on all sides will eventually disintegrate, it only being a question of the duration of the temperature. It is also evident that the superficial area of 4-inch cubes bears an exceedingly large ratio to the mass, and it is evident that the ability to resist heat on so small a mass, where the heat attacks it from all faces must be very considerably less than is the case in a structure where the heat strikes but one face. What is most needed is information which will solve the question of the thickness of this insulating material and establish the rate of conductivity of heat from the surface of a large mass into the interior. It is the intention of the Joint Committee on Concrete and Reinforced Concrete to carry on tests along these lines, and I feel quite sure that Professor Woolson will conduct further experiments and will propably be able to undertake some lines of investigation which will lead to the determination of the rate of conductivity of heat from the surface of a large mass towards the interior, with a view of determining the thickness necessary to properly insulate the embedded steel.

Mr. Talbot.

MR. A. N. TALBOT.—These tests of Professor Woolson go to confirm the opinion expressed last year that one of the reasons why concrete is a fire-resisting material is that it ranks very high in non-conductivity of heat; it is also plain that the small cubes exposed to fire on all sides do not give a proper test for this purpose. One reason why the test cubes will not give conditions applicable in practice is that the distance in from the face of these cubes is small, and that as the center of the test piece is approached the

area which the heat acts upon is decreased and the effect is very largely increased. It is also true that the expansion of the test piece at different distances from the face will be unequal; so we may expect great harm to be done to such a specimen. In buildings, thin sections like floors may not be expected to be subjected to fire on more than one side. **Mr. Talbot.**

In connection with the conductivity of concrete, it should, of course, be borne in mind that there are several conditions affecting the change of temperature which takes place through a piece of concrete exposed to high temperature on one side. There is the heat capacity of the material, time and a certain amount of heat being necessary to raise the temperature of the material itself. There is the conductivity of material, the rate of transmission of heat through the test specimen; and there is, of course, the radiation of heat on the other side. Now it seems to me that the curves that were given there, which Professor Woolson said were not a direct function of the distance, do really show that it is a direct function of the distance; in other words, that the heat gradient is a straight line. If you take that line down through vertically, the spaces are fairly uniform.

It seems to me that a method of testing slabs arranged so that the heat is applied on one side should be employed; and that additional tests, perhaps, should be made on test pieces of the form of columns, but arranged in such a size that the objectionable element which is present with the 4-inch cubes would not affect the results. We must bear in mind, also, that a 5 hour fire, exposed to a temperature of 1,500° F., is very extreme—a severe test; and even under these conditions, in the case of these test pieces, the side exposed to the fire did not get within, say, 300 ° of the temperature of the furnace itself. Attention ought to be called to the fact, too, that the test pieces which were exposed to the fire on one side gave crushing tests within 300 lbs. of the crushing tests of the specimens which were not exposed to the fire.

MR. C. W. BOYNTON.—I am a little surprised that Professor Woolson's gravel concrete showed no strength after being exposed to the fire; and I should be obliged for a little more definite information on this point. Was the concrete disintegrated, or the bond simply broken? **Mr. Boynton.**

MR. IRA H. WOOLSON.—The concrete was so tender that **Mr. Woolson.**

Mr. Woolson. some of the specimens broke to pieces taking them out of the furnace; the others were so manifestly weak that it was useless to put them into the testing machines.

Mr. Boynton. MR. BOYNTON. Yet limestone subjected to the same temperature was not so affected.

Mr. Woolson. MR. WOOLSON. No. I have no explanation to offer except the one suggested.

Mr. Boynton. MR. BOYNTON.—Did you determine the composition of the gravel?

Mr. Woolson. MR. WOOLSON.—No. It was Long Island gravel, that comes into New York assorted into different sizes; this varied from about one-fourth inch to half-inch size. It was exceedingly smooth and exceedingly clean.

Mr. Boynton. MR. BOYNTON.—Why should the heat affect the quartz gravel more seriously than a limestone of high carbonate?

Mr. Woolson. MR. WOOLSON.—I do not know.

Mr. Heidenreich. MR. E. LEE HEIDENREICH.—A few days before I left Chicago I received a sample of concrete from Shreveport, La. It was made of a gravel passing through a $\frac{3}{4}$ inch ring and was supposed to consist of 1 part cement, 2 parts sand and 4 parts gravel. I was asked what was the matter with the concrete; it broke to pieces like so much clay, and would not hold at all. The gravel was remarkably clean, having been dredged out of the river but although it was four weeks old I could break it in my hands; and the surfaces where the pebbles were torn off were absolutely smooth, almost as if glazed. The sand was entirely too fine; it was almost like quicksand, and contained a large amount of vegetable loam. This loam to my mind should never be permitted in any concrete. I have often noticed specifications, permitting from 5 per cent. to 10 per cent. of loam, and it is often claimed that it rather betters the result. I do not agree with engineers who permit any loam in concrete; because it is dangerous. If you give the devil one finger he most likely will take the whole hand. If it soils the hand in examining it, they will say: "It has a little loam, and a little loam is better than none". I think loam should not be permitted in concrete specifications.

I merely mention this in connection with the fact that Professor Woolson's samples crumbled so easily; and possibly it might be due to loam in the sand, or to too smooth gravel.

THE CHAIRMAN (MR. R. W. LESLEY).—That reminds the Chairman of a state of facts that developed the other day in the course of reading a paper on Ancient Roman and Etruscan Mortars; and in that connection he had the opportunity to examine a great many of the specifications of antiquity. It turned out on comparison that a specification made in Egypt for bricks would correspond practically with our specification for bricks to-day; and that a specification for lime would correspond with our specification to-day; and gathering from about a half-dozen of the best railroads specifications for sand and putting them in parallel columns with the specifications of Vitruvius for Sand, you could hardly tell there was any difference at all. The latter required a sand free from loam, and after describing that it must show no loam on the hand, he said, further, it must leave no discoloration on a white garment. So it shows the world has not moved much in these particulars. **The Chairman.**

MR. F. CONDIT.—May I express the opinion that the weakness of the concrete made of gravel was due not to the fact that the gravel itself is more seriously affected by heat than limestone or other forms of stone, but to the fact that the smooth polished surface of the gravel does not adhere as well to cements as the broken stone, limestone or trap, and to the other fact that the smooth surfaces of pebble or gravel do not compact as well together and do not remain as substantial as broken stone. It has been found in concrete work in New England where gravel has been used that broken stone resists the action of frost much better than gravel where smooth gravel is used. **Mr. Condit.**

MR. J. G. BROWN.—I should like to express the thought that perhaps the difficulty lies in the difference of conductivity of the different stones. I am very much under the impression that if you take pure silicious sand and put that in the sand-bath, the transmission of heat will be a great deal better than it would be if you used either limestone or trap; and perhaps on that account the heat would be distributed better throughout the block and would promote disintegration. I would ask whether the gravel itself showed any indications of splitting. Sometimes feldspar looks very much like quartz, but will fail very quickly in contact with fire. **Mr. Brown.**

MR. HUMPHREY.—I should like to ask Professor Woolson **Mr. Humphrey.**

Mr. Humphrey. whether there was any difference in the consistency of the gravel and the stone concrete?

Mr. Woolson. MR. WOOLSON.—Not so far as we were able to determine, as our intention was to have the consistency exactly the same in each case.

Mr. Humphrey. MR. HUMPHREY.—It is a noticeable fact that mortars composed of rounded grains of sand require less water to get them into a plastic consistency than is the case with sands having angular grains. This is equally true of concrete. It is, however, quite true that the round particles are more readily compacted than angular, and for this reason the destiny of mortars or concretes having round particles is greater than mortars or concretes in which the aggregate is angular.

The term "loam", which has been used in this connection is a constantly recurring question and it seems difficult to have it discontinued. "Loam", such as is generally understood, is a vegetable material which has a deleterious effect on mortars and concretes. Natural bank or river gravels contain large quantities of very finely divided material, a certain percentage of which will pass through a No. 200 sieve. This very fine material is popularly known as "loam." The term however, is a misnomer and a more appropriate term would be "silt." This fine material when not present in excessive proportions fills the voids in the mortar or concrete, thereby reducing the quantity of cement required and in many cases greatly enhancing the strength of the mass. If there is a very large quantity of this silt, and it is in a very finely divided state it will often coat the particles of sand and gravel, thereby interfering with the contact of the cement with the surface and reducing the bond.

The question of the roundness of the particle as compared with the angular fragments has nothing to do with the strength, since the bond is dependent upon the porosity of the surface, the cement in its plastic condition flowing into these pores and in setting binds the mass together. Cement will adhere to glass, iron and other smooth surfaces. These surfaces, however, are porous, which enables the cement to form a bond, and it seems reasonable to assume that the bond between two particles of material formed by the cement between them is largely dependent on the hardening of the cement and its ability to flow into the pores of the materials

which it binds together. As I have already said, it often happens that the little surface pores in the particles in bank gravel will be filled up by the very finely divided material or silt which of course will prevent the cement from getting in to form the necessary bond, and this will reduce the strength considerably. Such tests as we have made on gravel and crushed stone show that gravels give as good results in compression as crushed stone. In fact, they are generally a little higher. I think the reason why the gravel concrete gives higher results is that the round grains can be more readily compacted, forming a denser mass than is the case with crushed stone in which the particles are more or less angular. The use of an aggregate under ideal conditions is to have it thoroughly graded so that the voids are reduced to a minimum and properly filled. You should have in such a well graded mixture a certain per cent. of fine materials. Oftentimes bank sands and gravels contain a great quantity of fine materials, and these gravels can very often be much improved by washing out a portion of this fine material. Of course, there are all kinds of gravels, for instance the glacial gravels of Indiana, Illinois and Ohio contain a large percentage of limestone particles, and concretes made out of this material offer a very poor resistance to fire because the limestone particles are decomposed by heat by reason of the disassociation of the carbonic acid gas in the limestone particle. **Mr. Humphrey.**

It does not seem to me that a good gravel containing siliceous particles should be deficient in fire-resisting qualities, and I think that Professor Woolson should make other tests to establish the weakness which is shown by his test. I do not think it fair from a single test of gravel to draw sweeping conclusions as to the fire-resisting qualities of gravels. I see no reason whatever why concrete composed of round particles should behave any different than angular particles in the fire, and it would seem that there must be some error which Professor Woolson has not observed which gave the results he reports, and I certainly hope that he will make other tests of this gravel and let us have the benefit of those tests at our next meeting. In the meanwhile let us take this single test of gravel which has behaved so erratically and place it on the shelf to await the results of further tests before drawing conclusions.

MR. WOOLSON.—There were about a half-dozen tests of gravel **Mr. Woolson.**

Mr. Woolson. but only one in which we got the internal temperature. There were a half-dozen heated for strength purposes, from which we had hoped to get elastic properties; but they fell to pieces. I think the criticism very just; we ought not to depend upon the results of this test but simply report it as a fact.*

Mr. Meade. MR. R. K. MEADE.—In the manufacture of cement we grind the raw material, very frequently, with flint pebbles; and these pebbles often break up and go into the kilns. The temperature in the latter is a good deal higher than anything Professor Woolson noticed; and I find the pebbles have always changed. They become porous, milky white; and so friable that you can break them up in your fingers.

Mr. Woolson. MR. WOOLSON.—These were not affected.

Mr. Meade. MR. MEADE.—In connection with the limestone, I might say that limestone (or calcium carbonate) has a critical temperature below which it does not give off carbonic acid gas; and unless the material is heated up to that point (which I believe is above any of those which Professor Woolson gives in his tests), I can not see why heat should make any chemical difference at all. I believe the critical temperature of limestone is about 900° C., which is about 1,700° to 1,800° F., and it would have to be heated to this temperature before its conversions into lime could take place.

Mr. Boynton. MR. BOYNTON.—Was the strength of the gravel concrete on an unheated specimen determined?

Mr. Woolson. MR. WOOLSON.—Yes. I think it was about 2,700 pounds per square inch.

Mr. Boynton. MR. BOYNTON.—Then it seems to me it must have been the heat that destroyed that bond, and not the fact that the particles were smooth.

Mr. Walter. MR. L. W. WALTER.—I should like to suggest that in further tests in this line to determine the comparative value of limestone and gravel in concrete, especially as to fire resisting qualities, the boulders from this gravel deposit be crushed to determine whether

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*Since this meeting was held, a paper has been published by Mr. Sheppard of the British Fire Protection Association of London, in which he says the results of their tests are strongly against the use of gravel concrete as a fire-resisting material. This would appear to confirm the above result.

I. H. W.

the shape of the aggregate has anything to do with its adaptability for this class of work. It is characteristic of the gravel on and about Long Island to have a very smooth and almost polished surface. There is little or no vegetable mold in the gravel deposit; and it occurs to me that by crushing boulders of the same material it will show that the fire-resisting quality of the boulder or the gravel crushed is better than that of the average limestone. Mr. Walter.

A NEW DEVICE FOR THE MECHANICAL ANALYSIS OF CONCRETE AGGREGATES.

By Charles N. Forrest.

Various attempts have been made in the past to design a device for the mechanical sifting of sand and concrete aggregates, but many of these have been of little value, and have failed to yield results comparable with those obtained by manipulation of the individual screens by hand.

The device which is shown in the illustrations was recently perfected by Messrs. Howard and Morse, the well-known weavers of wire cloth, and has proved so satisfactory and convenient in the analysis of a large number of concrete aggregates, that it is considered worthy of the attention of others interested in similar lines of study. The apparatus as used in these tests is shown in Fig. 1. Fig. 2 shows a motor drive applied to the apparatus.

The device is made entirely of iron and may be arranged for either hand or power drive, accommodating any reasonable number of screens. The mechanical movements distribute the contents of the sieves over the entire screening area and provide a double sharp vertical movement or jog, which is quite necessary in order to free the meshes from those particles which would ordinarily remain in the apertures of the cloth, and to which in great measure the efficiency of the device may be ascribed.

It is apparent that these movements simulate very closely those obtained in hand manipulation of the individual screens and the data presented show very close agreement in results obtained by the two methods.

In handling such materials as Portland cement or dust, it has been found necessary to place a washer or a few shot in each screen, whether the sifting is done directly by hand or with the sifting device.

SAND.

Four 50 gram Portions.

	Hand.	Hand.	Machine.	Machine.
	Per cent.	Per cent.	Per cent.	Per cent.
Retained 10 mesh	None	None	None	None
" 20 "	.8	.6	.7	.6
" 30 "	2.0	1.5	1.4	1.5
" 40 "	2.8	3.0	2.2	3.0
" 50 "	8.2	9.2	8.7	9.0
" 80 "	38.8	37.9	38.2	38.0
" 100 "	32.8	33.0	33.5	33.4
" 200 "	12.0	12.0	12.5	11.8
Passing 200 "	2.0	2.0	2.5	2.5
	99.4	99.2	99.7	99.8

CEMENT.

Three 50 gram Portions.

	Hand.	Machine.	
	Fingers used on cloth.	1-in. washer in each screen.	Without washer.
	Per cent.	Per cent.	Pe. cent.
Retained 80 mesh	5.2	3.6	7.2
" 100 "	7.8	6.0	9.0
" 200 "	12.0	14.0	38.0
Passing 200 "	72.0	76.0	44.6
	97.0	99.6	99.4

CONCRETE AGGREGATE.

1 Kilogram.

	Machine.	Hand.
	Per cent.	Per cent.
Retained 1 inch	None	None
" $\frac{1}{2}$ "	21.0	20.9
" $\frac{1}{4}$ "	32.3	32.1
" $\frac{1}{8}$ "	8.5	9.3
" 10 mesh	1.3	1.3
" 20 "	2.4	2.8
" 30 "	2.6	2.4
" 40 "	4.3	3.2
" 50 "	3.8	4.5
" 80 "	8.2	6.8
" 100 "	2.2	2.8
" 200 "	4.6	3.2
Passing 200 "	8.3	9.1
	99.5	98.4
Loss	.5	1.6

FIG. 1.

FIG. 2.

THE PURDUE UNIVERSITY IMPACT MACHINE.

By W. K. Hatt and W. P. Turner.

The equipment of the Laboratory for Testing Materials of Purdue University includes three impact machines:

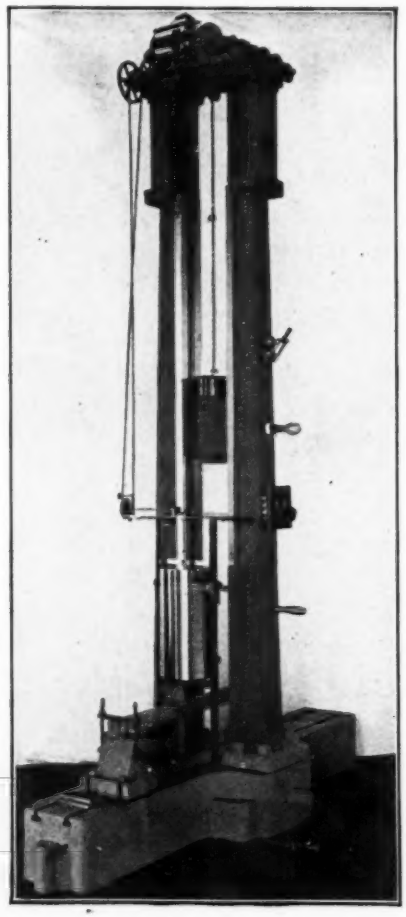


Fig. 1.

1. The Master Car Builders' Drop-Testing Machine, with a hammer of 2,000 pounds weight, an anvil of 17,000 pounds weight

Acknowledgment is made to the *American Machinist* for the cuts used in this paper.—Ed.

on springs, and a free fall of about 50 feet, designed for testing coupler, rails, axles, etc.*

2. An impact machine, mainly used in scientific investigations, designed for impact tests in tension and compression.† For the purpose of convenience this machine will be referred to as Tension Impact Machine.

3. An improved impact testing machine for scientific and standard tests in compression and flexure, described herewith, and called The Purdue University Impact Testing Machine.

The details of construction of this machine are the result of some years' experience, and constitute, in the opinion of the writers, a convenient and suitable instrument for university laboratories. The machine here described is the second one of its kind. It was devised especially for the operations of timber testing of the Forest Service, United States Department of Agriculture, and constructed through the Mechanical Department of Purdue University by W. P. Turner.

MAIN FEATURES OF MACHINE.

Briefly stated the elements of the machine are as follows:

Striking weights	50, 100 and 250 pounds.
Free fall	6.5 feet.
Length of flexure span	6.0 feet.
Weight of base	3,500 pounds.
Weight of column	700 pounds each.
Method of release	Electric.

The machine is shown in Figs. 1 and 2. The base is 7 feet long, 2½ feet wide at the center, and weighs 3,500 pounds. Two upright columns, eight feet long act as guides for the striking head. At the top of the columns is the hoisting mechanism, Fig. 3, for raising or lowering the striking weights. The power for operating the machine is furnished by a motor set on the top. The hoisting mechanism is all controlled by a single operating lever, shown on the side of column, Fig. 2, whereby the striking

*The Master Car Builders' Drop-Testing Machine, by W. F. M. Goss, Proceedings, American Society for Testing Materials, Vol. III., p. 256.

†Tensile Impact Tests, by W. K. Hatt, Proceedings, American Society for Testing Materials, Vol. IV., p. 282.

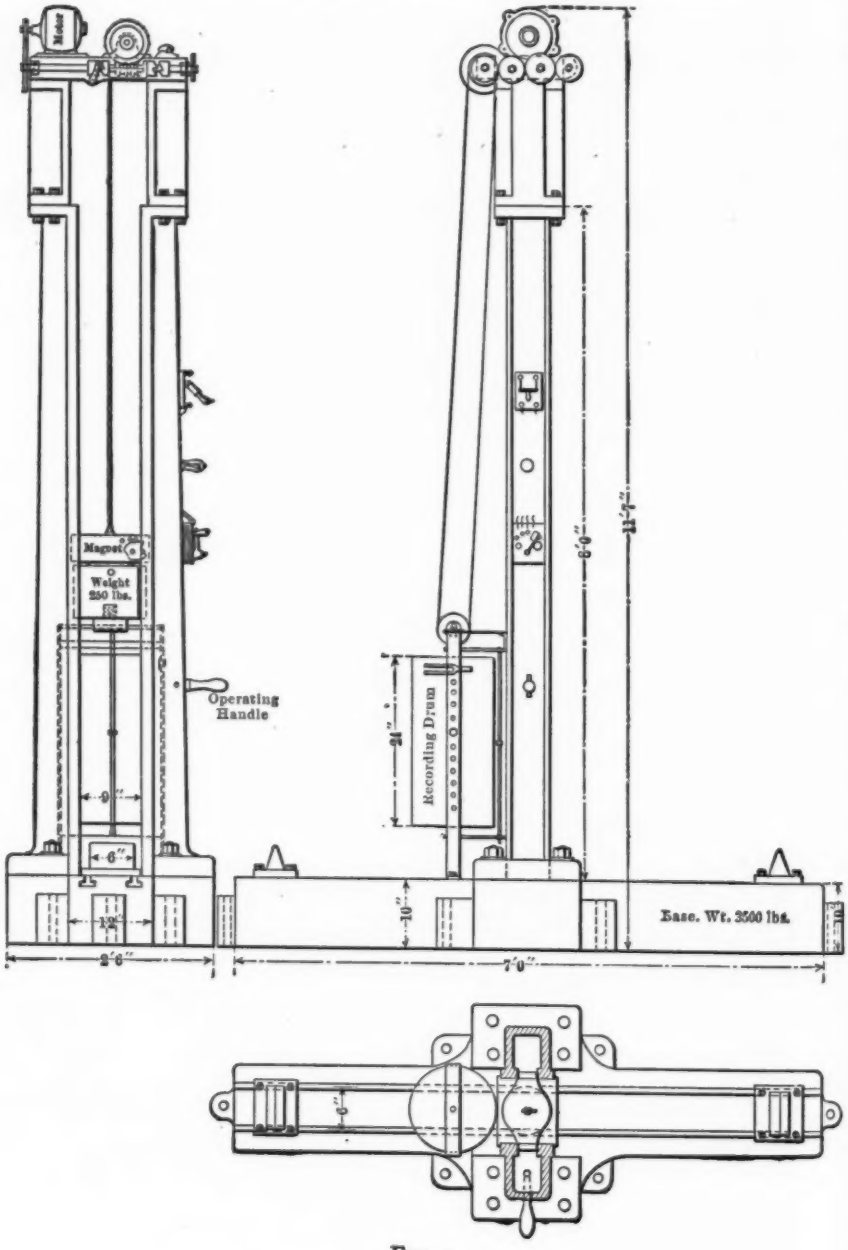

Motor
Magnet
Weight
250 lbs.
Operating
Handle
9"
6"
12"
2'6"
Recording Drum
24"
10"
6'0"
11'2"
Base. Wt. 3500 lbs.
7'0"
6"
R

FIG. 2.

weight may be raised, lowered, or stopped at any place at the will of the operator. The automatic safety device stops the machine

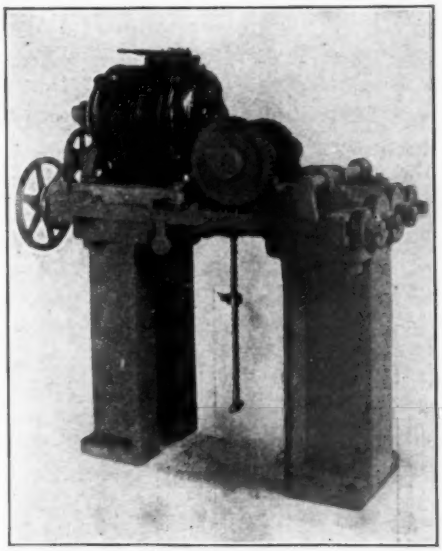


FIG. 3.

before damage is done, should the operator leave the operating lever in hoisting position.

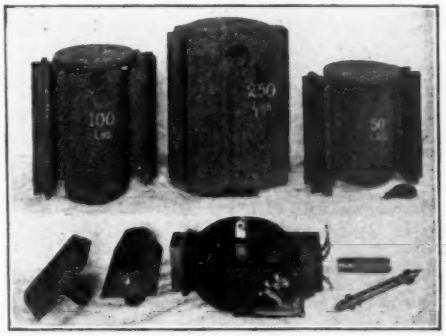


FIG. 4.

The weight is lifted by a chain, one end of which passes over a sprocket wheel in the hoisting mechanism. On the lower end

of the chain is hung an iron clad electric magnet, shown in Fig. 4, of sufficient magnetic strength to support the heaviest striking weights. When it is desired to drop the striking weight the electric current is broken and reversed by means of an automatic switch and current breaker. The height of the drop may be regulated by setting at the desired height, on one of the columns, a tripping pin which throws the switch on the magnet and so breaks and reverses the current.

There are three striking weights, weighing respectively 50 pounds, 100 pounds, and 250 pounds, any one of which may be used depending upon desired energy of blow. When used for

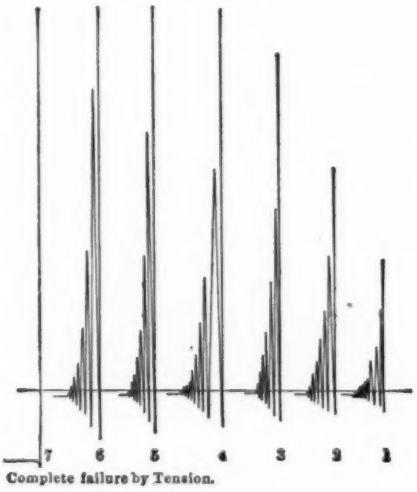


FIG. 5.

compression tests a flat steel head, six inches in diameter is screwed into the lower end of the weight. For transverse tests, a well rounded knife edge is screwed into the weight in place of the flat head. Knife edges for supporting the ends of the specimen to be tested, are bolted securely to the base of the machine. The record of the behavior of the specimen at time of impact is traced upon a revolving drum by a pencil, fixed in the striking head. The pencil shown in Fig. 4 may be used in any one of the weights. When in use the pencil is "set" by drawing it back so that the point does not touch the drum. When a drop is made a tripping

device releases the pencil at the proper time, and a spring holds the point against the revolving drum. Metallic paper is used on the drum, and a brass stylus is used in the point of the pencil.

Very small increments of compression or deflection have been accurately recorded, some as small as one hundredth of an inch. Such close and accurate records are made possible by eliminating lost motion between the weights and the guides, by using a suitable device for holding the recording pencil, and having a perfectly true revolving drum. The drum may be revolved either by hand or by power from the motor. The speed of the drum is recorded by the line traced upon the metallic paper by a stylus in the end of a tuning fork which gives a known number of vibrations per second.

The machine will handle specimens for transverse tests 9 inches wide and 6 feet span. For compression tests a free fall of about 6½ feet may be obtained. For transverse tests the fall is a little less, depending upon the size of the specimen. With the three sizes of striking weights the range of capacity of the machine is much increased.

CALIBRATION OF MACHINE.

An extended series of experiments was performed in the process of comparison of the three machines mentioned.

Lead and copper cylinders of various diameters were deformed in

(*a*) Static Machine.
(*b*) Master Car Builders' Machine. (With spring foundation.)
(*c*) Tension Impact Machine.
(*d*) Purdue University Impact Machine.

Measurements of deformation, accompanying loads, were made in static compression, and then similar original specimens of lead or copper were compressed under impact by hammers of various weights falling from various heights. The results of this investigation are too extended to reproduce in this paper, and will be reserved for another occasion. However, some part may be described.

(*a*) When a block of copper is compressed under gradual loading, and the amount of compression observed, the energy represented by the product of force and movement may be computed. The energy exerted along the axis of the specimen required to compress the copper to any particular degree of compression is thus known.

(*b*) If a similar block be subjected to the blow of a hammer in an impact machine, the external energy required to produce a given compression may be observed.

The two amounts of energy in (*a*) and (*b*) are not equal for,

1. A portion of the energy of the blow in (*b*) is used up in deforming parts of the machine, this portion not being very great in well constructed machines; and

2. The energy spent at right angles to the direction of the axis of compression, due in part to the spreading of the material against the head of the machine, is different in (*b*) and in (*a*).

3. The work required to produce the flow of the materials varies with the rate of distortion, being a function of the viscosity of the material and the weight of the molecules.

Consequently, impact tests show an apparent loss of efficiency compared with static tests, for the above reasons; that is to say, the production of a given amount of compression requires, under impact tests, an apparent greater external energy of falling weight than the energy measured under static conditions.

The losses in impact tests, due to friction of guides and deformation of machine, are small, and they vary but little under diverse circumstances. The work in over coming the resistance of the expanding head of the test piece against the hammer must also be small, since little difference is observed in the results, when the heads of the hammer are oiled and when they are rough.

There is, however, a wide difference between the energy delivered to the specimen by the hammer and the resulting compression-work, when the latter is assumed to be that amount required, under static conditions, to produce the compression following the blow. In the case of a copper cylinder 2 inches in diameter the compression-work produced was only 75 per cent. of the theoretical energy of the blow; a 1 inch diameter, 67 per cent.; 1½ inch diameter, lead, 36 per cent. The relative compression for a given drop in these cases was 1, 1.5 and 3.7.

One must not, therefore, conclude, as some have concluded, that "the efficiency of the blow," as it is sometimes termed, is the expression of losses of energy in the frame and foundation of the machine. The difference between the two amounts of energy required to produce a given axial compression is largely due to (1) the viscosity of the material, and (2) the energy used up in transverse deformation.

The results of the calibration are summarized in Tables I, II and III. The values quoted are obtained as follows:

The hammer was dropped on the copper plug and the axial compression noted after the blow. The energy used in static tests to produce this axial compression, under stress, in a like piece of metal was determined. The external energy of the blow (i. e. the weight of hammer times the height of drop) is compared with the energy used in static tests at equal amounts of compression. For instance:

Energy delivered, impact test .....35,000 inch pounds.
Energy computed from static test .....26,400 inch pounds.
Per cent. of efficiency of blow .....75·3

USES OF THE MACHINE.

There are three kinds of tests to be distinguished with respect to the time of application:

(*a*) when a determined load is applied to a test piece and allowed to remain for a long period of time; (*b*) when increasing loads are applied continuously and throughout a period of from 10 to 20 minutes until the piece fails; (*c*) when the load is applied through the medium of a blow under which the test piece fails in a short period of time measured by a small fraction of a second. Under (*a*) we have the case of a load such as is produced by books on a library shelf; under (*b*) we have the ordinary testing process from which the strength of materials to carry static loads is almost universally determined, and the test referred to as "static test"; and under (*c*) we have the case of a shock or impact such as occurs in parts of rolling stock.

The resistance of a material to impact is usually determined under a number of blows of increasing height. The successive amount of deformation and set of the specimen and rebound of the hammer are recorded on the drum. The elastic strength of the specimen is fixed at that limit at which the deflection suddenly increases, which limit is usually characterized also by a sudden increase in the set of the specimen and a maximum amount of rebound of the hammer.

In making the test the hammer is allowed to just touch the upper surface of the specimen, and a datum or zero line is then drawn on the

drum. The weight of the hammer is then allowed to rest upon the specimen, and the deflection under the dead weight of the hammer noted. The blows of increasing height of fall are delivered to the specimen, and records taken on the drum. A sample record is seen in Fig. 5.

The height of the drop at which any rupture of the specimen occurs is noted together with other phenomena of test. Sample log sheets and calculations will be found in Appendix I.*

The methods of computation of tests when specimen is broken under a single blow of the hammer are found in a paper by the writer in the Proceedings of the American Society for Testing Materials, Vol. IV., 1904, p. 282.

TABLE I.—TENSION IMPACT MACHINE. NO. 583 HAMMER.

Drop in feet.	Original height.	Final height.	Compression.	Theoretical energy delivered in inch pounds.	Energy absorbed as obtained from curve in inch pounds.	Absorbed energy in per cent. of theoretical.
			Copper: 1 inch diam.; 1 inch high.			
1	.975	.866	.109	7,025	3,810	54.2
2	.980	.762	.218	14,100	8,600	61.1
3	.969	.649	.320	21,180	13,950	75.5
4	.962	.560	.402	28,200	19,200	68.0
5	.962	.468	.494	35,100	26,400	75.3
6	.970	.415	.555	42,250	32,000	76.0
7	No test made.		.....	.....	.....	.....
8	" "		.....	.....	.....	.....
			Lead: 1½ inch diam.; 1½ inch high.			
1	1.500	.899	.601	7,000	2,912	41.8
2	1.500	.614	.886	14,500	5,275	36.2
3	1.500	.453	1.046	21,600	7,751	35.9
4	1.510	.353	1.157	28,600	10,800	37.8
5	1.511	.293	1.218	35,620	13,990	39.2
6	1.481	.243	1.238	42,700	15,280	35.8
7	No test made.		.....	.....	.....	.....
8	" "		.....	.....	.....	.....
			Copper: 2 inch diam.; 2 inch high.			
1	1.996	1.892	.104	7,020	4,480	64.0
2	2.020	1.844	.176	14,040	9,680	68.0
4	2.020	1.739	.281	28,080	20,000	71.4
5	2.018	1.692	.326	35,170	25,600	72.7
6	2.020	1.648	.372	42,200	31,500	74.5
7	2.020	1.610	.410	49,200	36,000	73.0
8	2.000	1.564	.436	55,500	40,500	72.9

*Quoted from Circular 38 of the Forest Service, "Manual of Instructions to Engineers of Timber Tests," by W. K. Hatt.

TABLE II.—PURDUE IMPACT MACHINE. TESTS ON COPPER CYLINDERS 1 INCH IN DIAMETER, 1 INCH IN HEIGHT.

50-lb. Hammer.

Drop in feet.	Original height.	Final height.	Compression.	Theoretical energy delivered in inch pounds.	Energy absorbed as obtained from curve in inch pounds.	Absorbed energy in per cent. of theoretical.
1	1.000	.990	.010	600	320	53.3
2	1.000	.977	.023	1,201	833	69.2
3	1.002	.963	.039	1,800	1,216	67.0
4	1.000	.946	.054	2,459	1,726	70.2
5	.999	.930	.069	3,002	2,270	75.0
6	1.000	.919	.081	3,600	2,755	76.5

100-lb. Hammer.

1	.975	.956	.019	1,201	576	47.7
2	.981	.935	.046	2,404	1,472	61.5
3	.998	.926	.072	3,607	2,497	69.2
4	.977	.884	.093	4,809	3,200	66.5
5	.977	.859	.118	6,011	4,162	69.2
6	.....	.....	.....	.....	.....	.....

250-lb. Hammer.

1	.977	.937	.060	3,006	1,952	63.8
2	1.000	.879	.121	6,020	4,280	71.2
3	.988	.823	.175	9,030	6,599	73.0
4	.999	.774	.225	12,040	8,972	74.5
5	.998	.727	.271	15,050	11,280	75.0
6	.997	.685	.312	18,060	13,520	75.0

250-lb. Hammer. Annealed Copper.

1	.999	.870	.129	3,006	2,498	81.5
2	.999	.803	.196	6,020	4,420	73.5
3	1.000	.751	.249	9,030	6,246	69.0
4	.997	.700	.297	12,040	8,260	68.5
5	.999	.661	.338	15,050	10,220	68.0
6	1.000	.621	.379	18,060	12,470	60.0

TABLE III.—PURDUE IMPACT MACHINE. TESTS ON LEAD CYLINDERS 1½ INCH IN DIAMETER, 1½ INCH IN HEIGHT.

50-lb. Hammer.

Drop in feet.	Original height.	Final height.	Compression.	Theoretical energy delivered in inch pounds.	Energy absorbed as obtained from curve in inch pounds.	Absorbed energy in per cent. of theoretical.
1	1.481	1.356	.125	605	328	54.2
2	1.484	1.295	.189	1,208	632	52.5
3	1.503	1.236	.267	1,810	992	55.0
4	1.505	1.180	.325	2,419	1,352	56.0
5	1.505	1.137	.368	3,199	1,575	49.5
6	1.509	1.085	.424	3,620	1,855	51.2

100-lb. Hammer.

1	1.498	1.315	.183	1,201	600	50.0
2	1.496	1.210	.286	2,402	1,120	46.6
3	1.502	1.135	.367	3,603	1,569	43.5
4	1.504	1.062	.442	4,804	1,950	40.5
5	1.490	.982	.508	6,005	2,320	38.4
6	1.502	.934	.568	7,206	2,794	38.6

250-lb. Hammer.

1	1.512	1.148	.364	3,091	1,552	50.2
2	1.511	.952	.559	6,140	2,640	43.0
3	1.509	.805	.704	9,175	3,680	40.2
4	1.513	.701	.812	12,202	4,600	37.6
5	1.509	.606	.903	15,225	5,712	37.4
5.98	1.506	.538	.978	18,183	6,944	37.0

250-lb. Hammer. Copper: 2 inch diam.; 2 inch high.

3	2.005	1.880	.125	9,020	6,000	66.5
4	1.996	1.845	.151	12,280	7,840	63.9
5	2.005	1.828	.177	15,200	9 760	64.2
5.98	2.004	1.805	.199	17,920	11,680	65.0

Appendix.*

METHODS OF OBSERVATION AND CALCULATION.

Formulas for calculating impact tests in flexure.

E = Modulus of Elasticity.

M Ri = Modulus of Resilience—inch-pounds per cubic inch.

F S = Fiber Stress—pounds per square inch at elastic limit.

W = Weight of hammer (pounds).

H = Height of drop in inches including deflection.

Δ = Deflection of stick in inches.

b, h = Width and depth of beam in inches.

l = Length of span—inches.

Moisture = Per cent. of moisture (upon basis of dry weight of wood) divided by 100.

Load applied at center up to elastic limit:

$$F S = \frac{3 W H l}{\Delta b h^2}$$

$$E = \frac{F S l^2}{6 \Delta h}$$

$$M Ri = \frac{W H}{l b h}$$

$$\text{Sp. Gr.} = \frac{\text{Wet Weight in lbs.} \times 27.7}{(1 \times \text{moisture}) \times \text{Vol.}}$$

In determining the elastic limit plot H against Δ^2. The elastic limit is that point where the height of drop (H) ceases to be proportional to the square of the deflection.

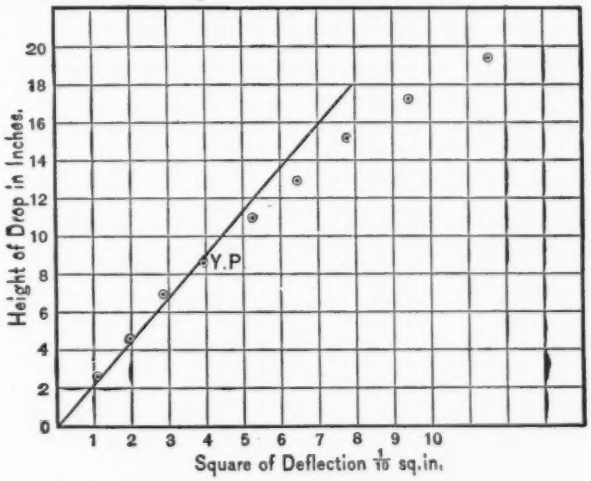


Fig. 1.—Impact Bending.

*Reproduced from Forest Service Circular, No. 38, "Instructions to Engineer's of Timber Tests," by W. K. Hatt.

IMPACT TEST—BENDING.

Lab. No. 3487 Series No. 109 Laboratory Purdue University

Species Pinus tæda Date of test March, 23, 1905

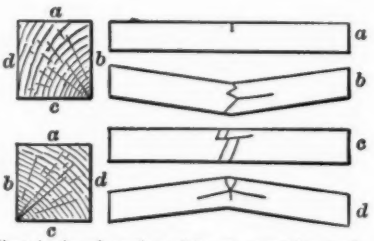
Stick No. 102–1043 Mark D–1

Width 2.05 in. Height 2.04 in.

Length 36.02 in. Weight 1,568 gr.

Rings per in. 7 Grain Straight

Per cent. of sap 100



Sketch showing disposition in machine and failure.

Grade Clear

Machine U. S. Impact Span 34 in.

Photographs

Defects None

Per cent. of moisture 28.9 Specific gravity (dry) .492

Fiber stress at maximum drop lbs. per sq. in.

Fiber stress at elastic limit 8,540 lbs. per sq. in.

Modulus of elasticity 1,300 1,000 lbs. per sq. in.

Modulus of resilience 3.112 in.-lbs. per cu. in.

Manner of failure Sudden tension failure

No. of blow.	Height of drop in inches.	Deflection in inches. d	Rebound in inches.	Set in inches.	Difference of head inches. H	$(d+d')^2$	Remarks. Weight of hammer 50 lbs. $d'=.02''$
1	2.26	.30	1.73	.00	2.56	.102	
2	4.26	.41	3.12	.01	4.67	.185	
3	6.26	.52	4.32	.02	6.78	.292	
4	8.26	.60	5.27	.03	8.86	.384	
5	10.26	.70	6.53	.04	10.96	.518	
6	12.26	.78	7.28	.05	13.04	.640	
7	14.26	.86	8.06	.06	15.12	.774	
8	16.26	.05	8.70	.08	17.21	.941	
9	18.26	1.05	9.26	.10	19.31	1.145	Complete failure by tension at center.
10	20.26						

IMPACT TEST—COMPRESSION.

Lab. No. *2613* **Series** No. *103* Laboratory *St. Louis*

Species *Pinus tæda* Date of Test *January 21–05*

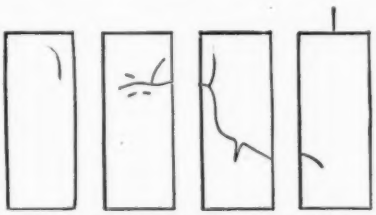
Stick No. *72–737* Mark *D–6*

Height *3.99* in. Cross sec. *1.99* in.

X *2.00* in.

Weight *280.2* Rings per in. *5 1-2*

Grade *Clear* Per cent. of sap *100*



Sketch showing disposition in machine and failure.

Machine *U. S. Impact* Photograph

Defects *None*

Per cent. of moisture *30.0* Specific gravity (dry) *0.496*

Crushing strength at yield point *47.7 inch*-lbs. per *cu in.*

Crushing strength at maximum drop *95.1* "-lbs. per "

Modulus of elasticity

Manner of failure *Shearing*

No. of blow.	Height of drop in inches.	Deflection in inches.	Rebound in inches.	Set in inches.	Difference of head inches.	Total energy absorbed in.-lbs.	Remarks. Weight of hammer 50 lbs.
1	3.08	.03	1.25				
2	6.10	.04	2.78				
3	9.10	.04	4.01				
4	12.10	.05	4.81				
5	15.10	.06	5.70	.01			
6	18.10	.06	5.95	.01			
7	21.10	.07	5.94	.01			*Slight shear at middle*
8	24.10	.07	6.64	.01			
9	27.10	.08	6.10	.01			
10	30.10	.10	5.40	.02			*Complete failure by shear*

NEW FEATURES OF TWO LARGE TESTING MACHINES.

By W. C. Du Comb, Jr.

It is the purpose of this paper to describe briefly a 600,000-lb. screw power testing machine and a 400,000-lb. hydraulic testing machine and to describe in detail the new features of these machines.

The 600,000-lb. machine is similar to the type known as the Riehle U. S. Standard Vertical Screw-Power Testing Machine; it is a universal machine, that is, arranged to make tests by tension, compression and flexure, and is especially adapted for tests of investigation. The University of Illinois, Champaign, Illinois, installed this machine about a year ago.

The 400,000-lb. machine is a Riehle Vertical Hydraulic Testing Machine arranged to make tension and hot or cold bend tests, and is especially adapted for rolling mill testing or where rapid testing is desired. One of these machines has been in use by the Bethlehem Steel Company, South Bethlehem, Pa., about a year, and one by the Republic Iron and Steel Company, East Chicago, Ind., about six months.

Description of 600,000-lb. Testing Machine.

This machine (Fig. 1) consists of two parts, the weighing apparatus and the straining mechanism; the parts which transmit the load from the specimen to the weighing system rest on the weighing table and are not connected in any way to the parts which apply the load.

The weighing apparatus is of the knife-edge lever system, consisting of four main levers, first and second intermediate levers and micrometer screw beam. The back pivots and the main lever are supported by steel bearings in lugs on the cover plate "D" (Fig. 2), and the cover plate is secured to two legs which rest on the foundation plate. The weighing table "A" rests on the middle pivot in the main levers and the weighing columns "B" are secured to the weighing table. These columns are held

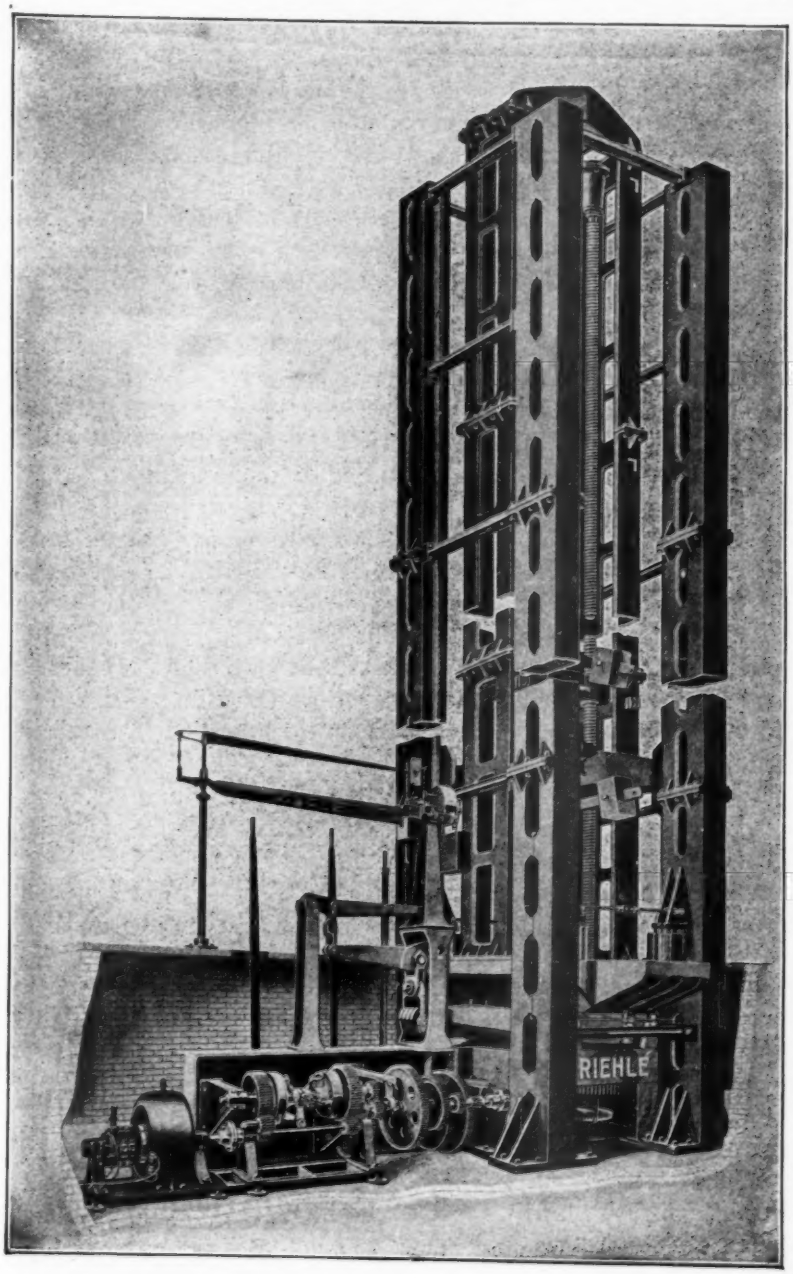


FIG. 1.—General View of 600,000 lb. Testing Machine.

together at the top by a tie-head and support the tension weighing head "C" at any one of three positions.

A new feature is the design of the main levers (Fig. 3); these are steel castings, four in number, and they are proportioned to secure as uniform deflection and as even distribution of load over the knife edge as is possible. In order to obtain the latter the center of the front, middle and back pivots lie in the same center line, transmitting the load in this line, and each lever is split into two webs with knife-edge bearings between and on each side of the webs.

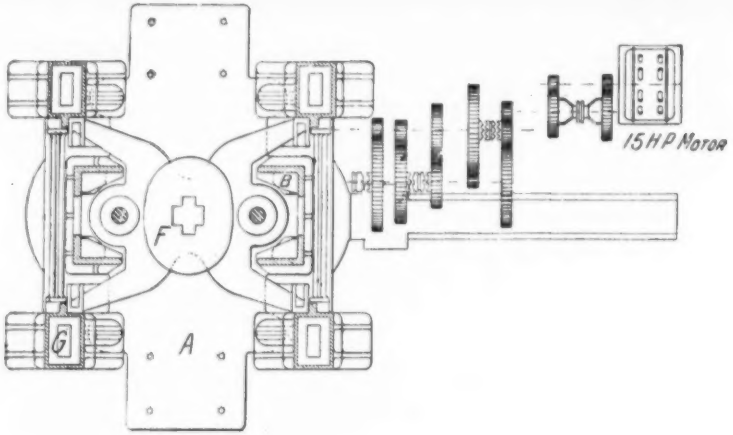
The performance of the main levers under test was satisfactory, the deflection in all the levers being such as to permit the table to remain level when the machine was loaded to its capacity. Under full load the table was lowered about .05 inch. The weighing beam is a micrometer dial-screw beam graduated in 10,000 lb. marks and reading to 100 lbs. on the dial. The main poise moved to the proper position on the beam records 600,000 lbs. An auxiliary poise reading $\frac{1}{10}$ the capacity of the machine can be placed on the beam and operated independently of the main poise.

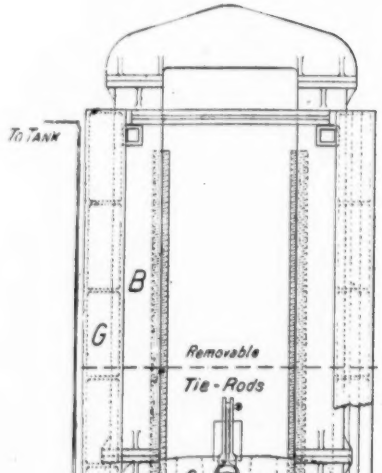
The hand wheel which turns the beam screw is provided with change gears so that the poise used can be moved on the beam at one of two speeds, the ratio being five to one. This is a new feature and is desirable on a machine of this kind in order to readily control the beam for various tests. The total count of the lever system is 5,760, so the main poise weighs 104.432 lbs.

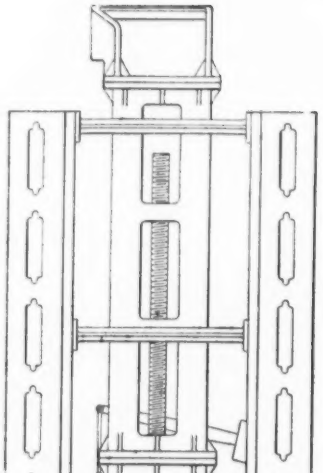
A needle beam is used to magnify the swing of the weighing beam ten times, thus increasing the sensitiveness of the lever system. The importance of the needle beam is shown by the following: Under no load a 50-lb. weight placed on the table of the machine settled the point of the needle beam $\frac{7}{8}$ inch above the balance line and under full load in tension the same weight settled the point of the needle beam $\frac{5}{8}$ inch above the balance line, and moving the poise on the beam produced like results.

An interesting feature is the extreme sensitiveness and accuracy under all loads; this was exemplified by weighing a man on the machine as 145 lbs., actual weight on scales 146½ lbs., the machine was loaded to 60,000 lbs. by calibrating levers and weights when this test was made. While the machine was loaded to 600,000 lbs. in tension, Professor Talbot stepped on the weigh-

PLATE XXII.
PROC. AM. SOC. TEST. MATS.
VOLUME VI.
DU COMB ON TESTING MACHINES.







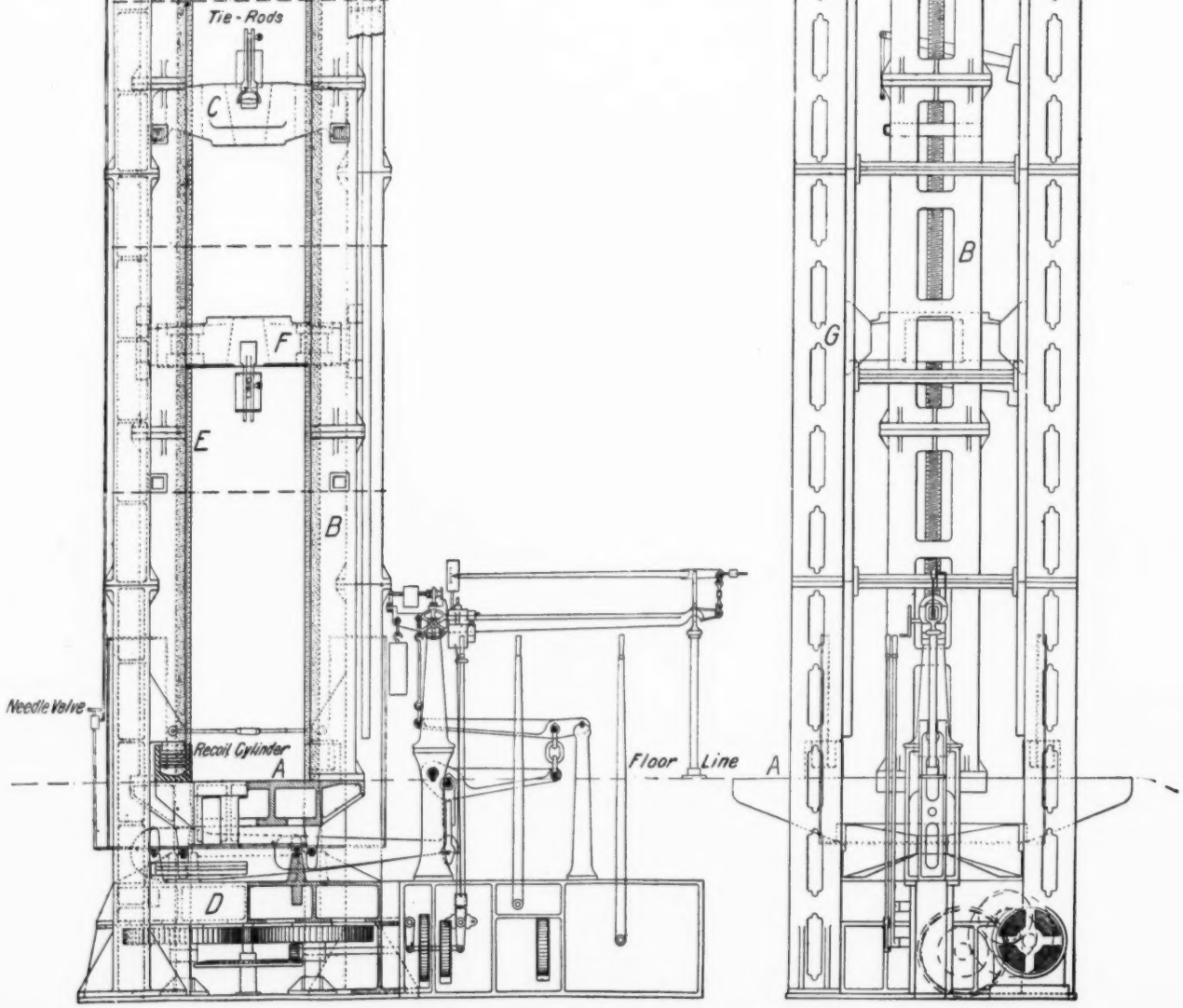


FIG. 2.—Details of 600,000 lbs. Testing Machine.

ing table and was found to weigh 152½ lbs., time allowance being made for loss of load of machine, actual weight on scales 152½ lbs. For these tests the beam was operated by the author who

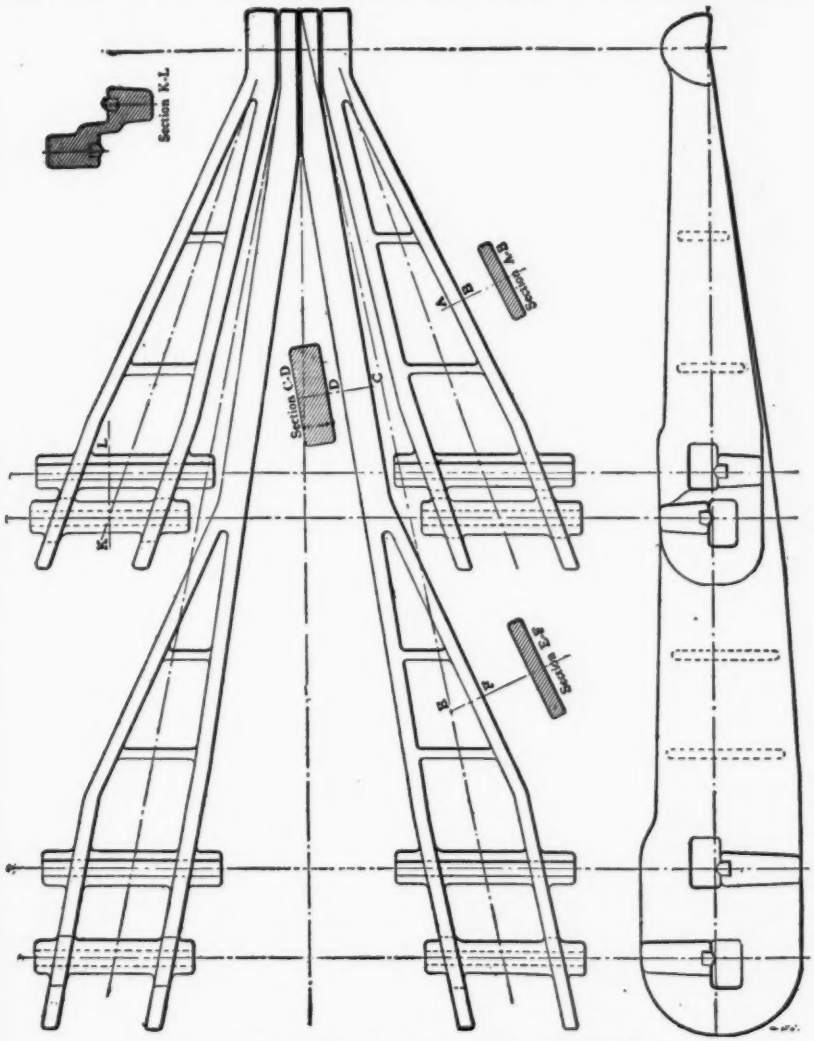


FIG. 3.—Levers for 600,000 lb. Testing Machine.

stood in such a position that the dial of the beam on which the readings were taken was not visible, the beam being brought to balance by observing the point of the needle beam.

The straining mechanism is similar to that used in other Riehle testing machines. Load is applied to a specimen by the pulling head "F" which is moved up or down by the two pulling screws "E" rotating in bronze nuts secured in this head. The pulling head has four projecting arms provided with flat bearing surfaces which run in vertical guides on each side of the four guide columns "G." These columns extend to the highest point reached by the pulling head on its travel, and are an important feature of this machine. They are cast iron and designed to resist the side thrust and tipping of the pulling head which occurs in making compression tests, and also to resist any tendency of the pulling head to rotate due to friction of the screws in the nuts. Bolts secure these columns to the foundation plate, legs, and cover plate, and struts are provided at suitable intervals so that the four columns take the side thrust as a single column. These columns will carry a side thrust of 10,000 lbs. at the top or of 20,000 lbs. 12½ ft. from the top, and a specimen can be loaded to the full capacity of the machine 5 in. out of center or 5 in. eccentrically; this condition might occur, due to failure on one side of a specimen or when testing irregular shapes. It should be borne in mind that these columns are not in contact with any part of the weighing system.

The screws are driven through gearing by a 15 H. P. motor. Six speeds in either direction are provided, speed changes being made by means of positive clutches; duplex friction clutches are used to start, stop and reverse the rotation of the screws. The gears, all of which are cut, consist of one train of bevel-gears, the remaining train being spur gears. An important feature is the accessibility of the gearing for inspection, and the ease with which it may be taken apart without dismantling the machine.

The maximum fiber stresses in the materials used are as follows: Cast iron, 4,000 lbs. per square inch; bronze castings, 7,000 lbs. per square inch; steel castings, 12,000 lbs. per square inch; special forged steel 20,000 lbs. per square inch.

The recoil on a machine of this capacity is a serious problem, and the method used on this machine to prevent damage from the knife-edges is a new and distinctive feature. The energy produced by recoil amounts to about 40,000 inch lbs. when a tension specimen is tested to destruction at 600,000 lbs. With-

out some means of checking the recoil this energy would be employed in lifting the weighing parts of the machine into the air, and returning them in the form of a blow on the knife edges.

The recoil is dissipated by fluid friction in the following manner. Four steel cylinders (Fig. 4) 8 in. diameter, rest on the weighing table, into each of which is fitted a plunger which is attached to a bracket on a guide column. The space in the cylinders is filled

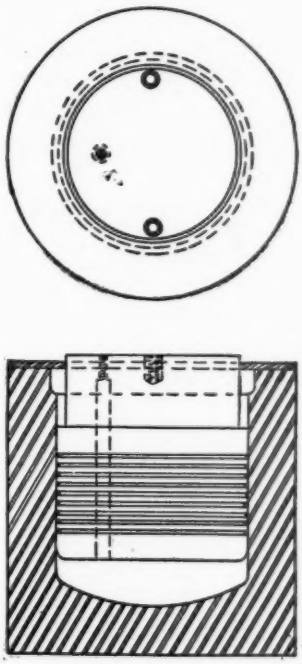


FIG. 4.—Recoil Cylinder for 600,000 lb. Testing Machine.

with oil supplied from a tank on the top of the machine by suitable piping, maintaining a constant pressure of about 10 lbs. per square inch in these cylinders. A valve with an aperture which may be regulated is placed on the main supply pipe. When the machine is loaded the weighing table moves down, oil flowing into the cylinders through the aperture in the valve; upon the rupture of a specimen the weighing table tends to rise and the

oil is forced back through the valve, fluid friction absorbing nearly all the energy of recoil.

Since installation the University has supplied the machine with an elevator, which surrounds three sides and runs in ways bolted to the guide columns. In order to protect the weighing beam a case with a glass front has been provided.

The machine was designed by Riehle Bros. Testing Machine Company under the supervision of Prof. A. N. Talbot, to whom acknowledgment is hereby made for his valuable suggestions to the company both in general and detail design, thus contributing largely to the success of the machine. In conclusion it may be said that tests made on the machine proved it to be satisfactory as to accuracy, sensitiveness, eccentric loading, recoil and power.

Description of 400,000-lb. Testing Machine.

The weighing apparatus of this machine (Fig. 5) is of the knife-edge lever system, consisting of main lever, first and second intermediate levers, and micrometer dial screw beam. The weighing head "B" is suspended from the back pivot of the main lever "A," the middle pivot is supported by steel bearings in an arch piece which is secured to the side frame, these are bolted to the bed plate which rests on the foundation. A noteworthy feature is the design of the main lever to secure an even distribution of load on the knife edges.

The weighing beam is a micrometer dial screw beam graduated in 10,000 lb. marks, reading to 100 lbs. on the dial. The main poise moved to the proper position on the beam records 400,000 lbs. The total count of the lever system is 6,857$\frac{1}{7}$, so the poise weighs 58,333 lbs.

The recoil is transmitted from the weighing head to the bed plate by two rods "F" and is absorbed by the foundation.

The straining mechanism is of the hydraulic type, the pulling head "C" applies load to the specimen and is held by nuts to the upper ends of the two pulling rods "E," to the lower ends of these rods a cross head is held in the same way, this cross head is secured to a piston plunger working in the cylinder "D" which is bolted to the bed plate. The area of the return end of the cylinder is one-third that of the pulling end, so that the pulling head can be returned three times as fast as a specimen is pulled.

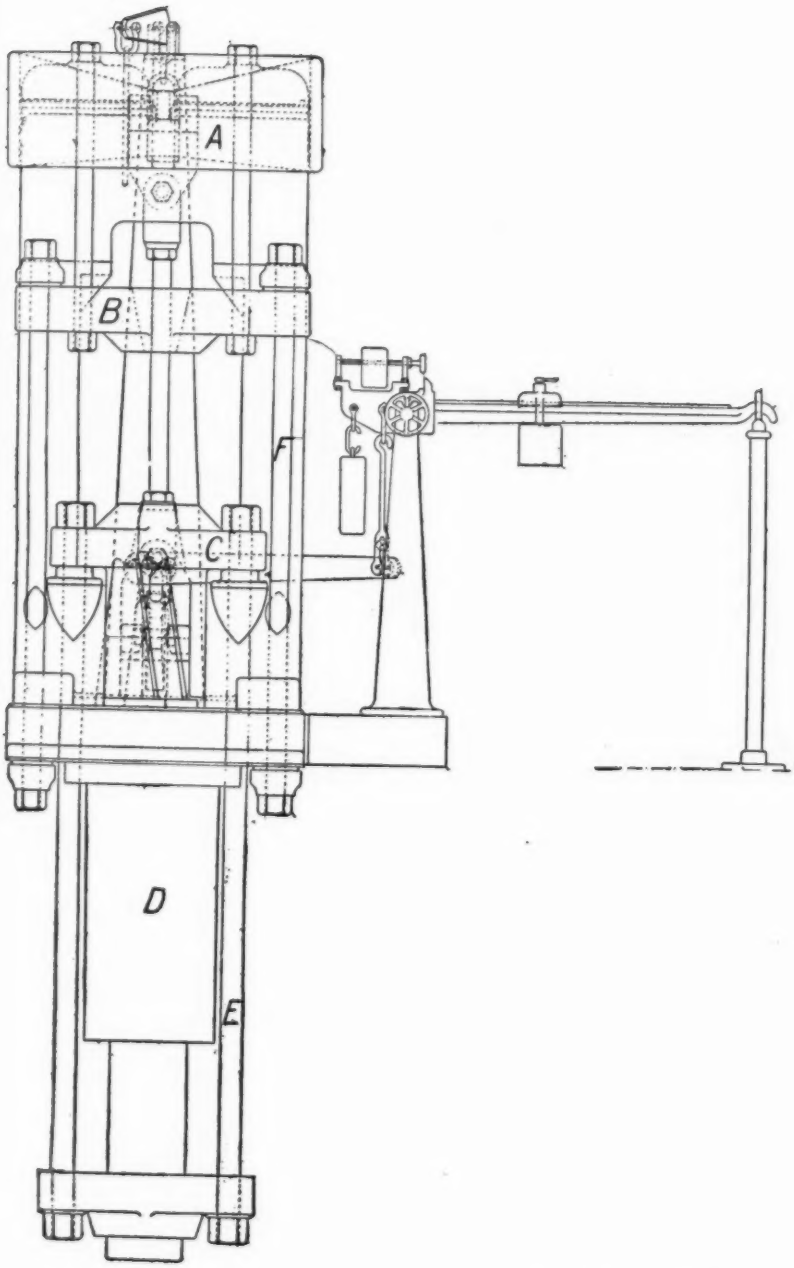
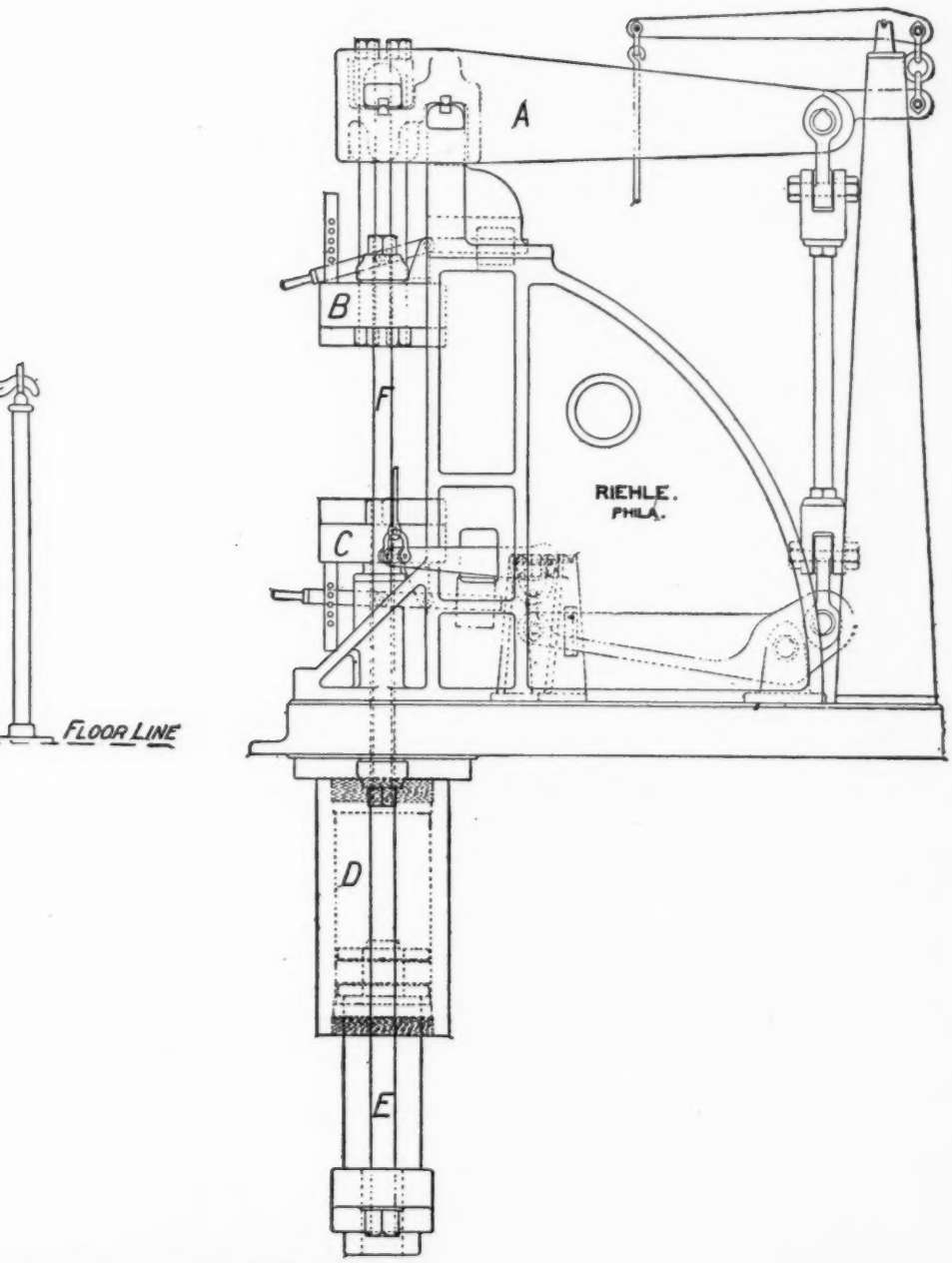


FIG. 5.—Details of 400,000 lb



400,000 lb. Hydraulic Testing Machine.

The pressure for operating the machine is furnished by a three-plunger hydraulic pump, a pressure of 2,300 lbs. per square inch being used to obtain 400,000 lbs. load on the machine. The pump is driven by a 10 H. P. variable speed motor, 4 to 1 variation, giving speeds ranging from 1½ to 6 in. per minute for pulling to the capacity of the machine, and from 4½ in. to 18 in. per minute for returning the pulling head.

By means of an operating valve the pulling head is run in either direction or stopped, speed changes being obtained by the motor controller.

In the opinion of the author a variable speed motor drive in connection with a testing machine is desirable, inasmuch as it is not necessary to stop loading a specimen in order to increase the speed of loading, and shock to the specimen, caused by suddenly starting up the machine when a specimen is under load, is avoided.

A machine for testing tension specimens whose ultimate strength is as high as 400,000 lbs. which can be used to make a number of tests in a short time and which will work to its capacity without frequent repairs has been required by rolling mills and manufacturers for some time. At the suggestion of Mr. Maunsel White, of the Bethlehem Steel Company, Riehle Bros. Testing Machine Company designed a machine to meet these requirements. The machine just described has so far proven satisfactory for work of this kind. Since building the first machine, Mr. L. W. Crane, of the Republic Iron and Steel Company, suggested attaching forms to make hot or cold bend tests, this is a valuable addition to the machine.

The principal new features of this machine are: Accessibility for placing a specimen in the machine, ease with which speed changes are obtained, rapid speeds for pulling and for returning the pulling head, and the comparatively small amount of power consumed for a given amount of work done. These features make a hydraulic machine seem most desirable for rapid testing.

DISCUSSION.

Mr. Talbot.

MR. A. N. TALBOT.—Regarding the 60,000 pound machine that has been described, I will say that we have put it to considerable use in tests in tension, compression, and crossbending, and have found it to be quite satisfactory. The form of lever used, the recoil cylinders and the guide beams have all been found to be suitable for the purpose. I know that there is a feeling in some quarters that it is not necessary to have a machine as accurate or as sensitive as this one has been found to be. This may be true for certain determinations of ultimate load, particularly in commercial testing. On the other hand, in scientific work, with certain kinds of investigation, at least, the effect of an increment of load may be of considerable importance; and it was for this use that I specified a certain accuracy and certain sensitiveness in this machine at higher loads. The method of calibrating the machine up to its full capacity by the use of the nickel steel test-bar 20 feet long was also quite satisfactory. The amount of the modulus of elasticity of course, was determined from the stretch of the test piece with a 60,000 pound load, the machine having been first calibrated to that amount by means of proving levers and weights.

Mr. Du Comb.

MR. DU COMB.—I might add to Professor Talbot's statement in regard to the calibrating bar that it is 4″ in diameter, the greatest variation being 0.0006 inches and the average variation only 0.00018 inches, so the stretch would be very uniform throughout the length of the bar.

A number of tests were made to prove the effectiveness of the guide columns, which are an important feature of the machine, inasmuch as they both hold the pulling-head parallel to the table and prevent it from twisting. When testing concrete columns or concrete cubes, if the pulling head is moved out of parallel with the table and if there is any twisting of the head, stresses are set up in the specimen which are not measurable. Errors of this kind can be avoided by rigidly guiding the pulling-head as is done in this machine. There are no doubt other methods for preventing tipping and twisting of the pulling-head, but the use of four guides columns, one at each corner of the pulling-head, is the surest way to secure rigidity.

THE OPERATIONS OF THE FUEL TESTING PLANT OF THE UNITED STATES GEOLOGICAL SURVEY AT ST. LOUIS, MO., FROM MAY 1, 1905, TO JULY 1, 1906.

By Joseph A. Holmes.

The appropriation by Congress of $202,000 on March 3, 1905, "for the analyzing and testing of coals, lignites, and other fuel substances of the United States, in order to determine their fuel values, etc., under the supervision of the Director of the United States Geological Survey," made it possible to resume on May 1, 1905, the investigations begun during the Louisiana Purchase Exposition at the testing plant in Forest Park, St. Louis, Mo.

The work was carried on under the direction of the General Committee appointed by the Director of the Geological Survey consisting of C. W. Hayes, J. A. Holmes, E. W. Parker and M. R. Campbell, with J. A. Holmes expert in immediate charge.

The principal branches of the work carried on include: (1) Sampling, (2) Chemical analysis, (3) Washing tests, (4) Coking tests, (5) Gas producer tests, (6) Steaming tests and (7) Briquetting tests.

Only special features of the work mentioned will be pointed out, the detailed and complete records being available in the printed reports issued by the Geological Survey.

Application forms "to have coal tested at the United States Geological Survey Coal-testing plant at St. Louis, Mo.," were sent to each operator of a shipping colliery in the United States.

A descriptive circular accompanying these forms set forth the conditions under which coal might be furnished for testing purposes as follows:

1. The coal must be furnished to the government testing plant free of cost to the government.

2. The coal must be loaded under the supervision of one of the inspectors employed for the purpose, who shall be allowed

at the same time to visit the working places in the mine to secure samples for analysis.

3. When it is possible to do so, the coal should be loaded in box cars and shipped under seal. Lignites must always be shipped in this way.

4. Where the market requires screened coal, this grade will be accepted for tests. The selection of coal is always to be under the direct supervision and control of the representative of the testing plant.

5. Where one of the problems involved is the better utilization of slack coal, a carload of slack may be accepted for testing purposes.

6. As soon as possible after the tests are completed a brief statement of the results will be furnished to parties supplying the coal, for their information but this must not be made public until the results are published by the Geological Survey.

7. Everyone interested in any particular test or in the general operation of the plant is invited to be present at any time but the official record of the tests will not be given out except as indicated in the preceding paragraph.

Applications were received from twenty-two states and one territory.

The collection of samples was very thorough, the methods having received much thought and study.

Chemical Analysis.—Two or more samples were taken for chemical analysis at the mine and shipped in special hermetically sealed cans.

The description of the routine work of the laboratory and general methods used in making chemical analysis of coal may be found in Bulletin No. 261, 1905, U. S. G. S., and Prof. Paper No. 48, 1905, U. S. G. S.

From May 1, 1905, to July 1, 1906, over 1,800 samples were received and 9,251 determinations were made.

The proximate analysis and sulphur determinations have been made on practically all of these and the ultimate analysis, determinations of the heating value and other special determinations have been made on such of the samples as have required the additional work.

Washing Tests.—The washing tests have shown how the

quality of forty-three coals from thirteen states and several samples of coke breeze could be improved by washing at a normal cost of from three to ten cents per ton.

Some have been washed for steaming purposes only, and some for both steaming and coking purposes.

In general it may be stated that washing coal increases the per cent. of moisture and volatile matter, decreases its ash and sulphur in coking, and increases its heating value for steaming coals.

Coking Tests.—In the coking tests, the coal unless otherwise requested was passed through a Williams Mill, crushing it so that it all passed a No. 10 mesh screen.

The sample of coal was taken for chemical analysis as the oven was loaded and samples of the resulting coke were taken from five different parts of the oven, these separate samples extending the whole height of the charge.

One hundred and fifty-seven tests were made of seventy-nine coals from seventeen states, each test being of from forty-eight to seventy-two hours duration. Of these coals a large proportion have heretofore been considered non-coking.

These investigations, in addition to demonstrating how many of the so-called non-coking coals of the United States may be coked by exercising increased care either in the construction or in the operation of the ovens, have also shown how the quality of the coal may be improved by the addition of pitch or other volatile hydro-carbons to the coal before being charged into the oven.

Gas-producer Tests.—The operating conditions from May 1, 1905 to July 1, 1906 have been far superior to those that were possible during the Exposition period of 1904 and the methods have consequently been subjected to refinements that were not attainable in the previous operation of the plant.

The determination of the amount of coal actually burned in the producer for any given period is, at best, a factor of more or less uncertainty.

To reduce the possible error to a minimum, it was deemed necessary to make the test on each coal as long as consistent. Accordingly a schedule was adopted at the beginning of this series of tests involving two sixty-hour runs per week. The first eight to twelve hours of each test period was used for getting the fuel bed into uniform and efficient condition. During these

preliminary hours, records were taken as in the regular tests, but the official test as reported, included only the last forty-eight or fifty hours of the run, during which time the conditions were maintained as uniform as possible.

In the period mentioned ninety-one tests on the gas-producer and gas engine were made, of coals, lignites, and peats from eighteen states, each test extending over two or three days.

The results show records as low as 0.95 pound of dry coal per hour burned in producer per electrical horse power developed at the switch board, or 0.80 pound of dry coal per hour burned in the producer per brake horsepower, on the basis of an assumed efficiency of 85 per cent. for generator and belt.

It was found at an early date that more or less sulphur was passing the purifier and entering the engine cylinders. Investigations by the chemists showed that purifiers consisting of oxidized iron filings and shavings are fairly efficient for coals containing little sulphur, one per cent. or less; but it was found that for coal containing larger percentages of sulphur, the purifier became completely exhausted after about six or eight hours. Mixtures of lime and shavings were tried, but with little success. As a result of these investigations the purifier has been discarded, and the gas carrying the full percentage of sulphur has been charged directly into the engine cylinders.

This method of operation has been going on for many months and no ill effects have been discovered, although coal has been used containing as high as 8.1 per cent. sulphur.

These producer-gas investigations have shown the suitability of bituminous coals, lignites, and peats for power purposes in the gas producer and gas engine.

While there remain difficulties in the way of the general introduction of this new source of power, yet the results of these investigations have already contributed in an important degree toward the overcoming of these difficulties, and serve as a basis of plans for new power developments in many parts of the country.

Already, fourteen or more different companies are reported to be making producers for power purposes and others are endeavoring to perfect new designs.

It may also be added that at two of our great steel plants blast-furnace gas engines have been introduced for power purposes

and a dozen companies are now either manufacturing or working on plans for the manufacture of gas engines.

Steaming Tests.—The only important change introduced in the test procedure consisted in making three trials with each coal, but the three ran so nearly alike that hereafter only two will be made. In the first series but one trial was made with each coal.

Special tests with mixed and dried coals, and twenty-four hour runs indicate a slightly higher boiler efficiency, but at present these investigations have not been carried far enough to warrant a positive statement.

In the period covered 282 tests of ninety-six different coals from twenty states have been made in the steam boilers, each test being from nine to eleven hours duration.

Briquetting Tests.—In the briquetting plant a number of new, possible binding materials for briquettes have been investigated; and a few of these have proved sufficiently satisfactory to warrant further investigation as to their more extended use, at a probable cost considerably less than that of coal tar pitch, which is ordinarily used in briquetting operations.

A number of lignites, representing both the extreme northwest and southwest, have been briquetted under high pressure without the use of binding materials and it has been shown that the cost of briquetting such materials should not exceed fifty cents per ton.

Furthermore, it has been shown, in the use of certain briquetted coals for railroad and domestic purposes, that the increase in the efficiency of the coals used in the briquetted form is more than sufficient to cover the cost of the briquetting operations.

During the period from May 1, 1905, to July 1, 1906, forty-six briquetting tests of nineteen different coals from eight different sources have been made.

The scope of a paper of this general character is necessarily limited to brief statements of fact. Fully detailed information may be obtained in the preliminary and final reports of 1904, and those for the year ending December 31, 1905, issued in Bulletin form by the United States Geological Survey.

The great value of these investigations in solving the problem of reducing the present criminal waste of coal under inefficient conditions, cannot be over estimated.

PRACTICAL TESTING AND VALUATION OF JAPAN.

By Robert Job.

Some years ago an investigation was begun at the Test Department of the Philadelphia and Reading Railway to devise a method by means of which the quality of the shipments of japan drier could be regulated and held to a proper standard.

The study was begun, owing to difficulties which occurred at the shops in the drying of the paint. In some cases the drier was deficient in strength, and it was then impossible to turn out work within a reasonable time. In other cases the addition of the drier caused curdling of the oil, with result of very slow drying of the paint and also great loss in the durability of the coating.

In order to gain information upon the subject, a large number of japans were obtained, and analyses and tests of strength made of each. Some were found to consist of little more than benzine, with gum or rosin added as a hardener, while others were composed of lead and manganese compounds of linseed oil with or without shellac or gum, and thinned with turpentine and some also contained varnish of varying degrees of quality. There was a marked difference in composition, and in efficiency in effecting drying of oil. Some of the japans were intended to act almost entirely as "hardners," that is to hold the paint film in position by means of gum or resin on evaporation of the solvent, while others depended upon the chemical drying of the oil, and still others were hardeners as well as chemical driers.

Upon studying the conditions under which the paint might be applied in service, we found that the coating must be dry enough to second coat within twelve hours or so, also that the paint must "set" sufficiently to prevent dragging down of the pigment—streakiness of the work—even when the conditions were very unfavorable, as for instance, in cold, damp weather.

These conditions meant that the main dependence must be placed upon a true chemical drier of the oil, and also that a certain amount of shellac or gum must be present to give the necessary

slight initial "set" to the film within a relatively short time. In other words our drier must act both chemically and mechanically.

Further study of the causes of curdling proved that in some cases the defect was due merely to the fact that the japan was in too concentrated a condition to diffuse through the paint on mixing for use, and in several instances we were surprised to find that quicker drying of the paint could be obtained when the samples of japan were diluted considerably with turpentine before mixing with the oil. The reason was that in its original condition the japan was so concentrated that it refused to dissolve in the oil to a clear solution, but instead formed clots. In other words, the full value of the japan was not utilized since the portions in the clots were covered up and withheld from union with the oil, thereby making a poorly blended mixture. When these same japans were diluted with turpentine, they were given a mechanical condition of fluidity which enabled them to mix perfectly with the oil to a clear solution. In the latter case the entire mass of the drier was utilized, and hence its full drying value rendered effective.

The economic bearing of this difference will be apparent when we consider that the solid driers are by much the most expensive constituents of the japan.

Upon study to devise a system of test by means of which each shipment of the material might be kept of uniform quality and of the desired properties, it was clear that mere chemical composition would tell very little regarding efficiency, since the latter would be largely dependent upon the conditions of manufacture. Therefore, we decided to leave the question of composition and of relative proportions to the manufacturer with very few restrictions, placing dependence upon the physical properties of the finished material, and making these properties conform to those found essential to produce the results desired. Obviously, a standard test for determining the chemical oil drying strength of the japans was of prime importance. It was essential that the details be so simple that the test could be made by the manufacturer before shipment of the material, and at the same time they must be so devised as to render possible close duplication of results by different observers in different places, and under different conditions of weather and of humidity.

After some study and experimentation we decided to make the

test by mixing the japan with pure raw linseed oil, in specified proportions, flowing the mixture over a clean dry glass, about four inches long by two inches wide, and placing the glass nearly vertical in an oven maintained at a temperature of 100° Fahr. by a small gas burner. The glass was kept in such a position that there would be a free access of air, but no draught, and the film was tested from time to time by a quick, firm pressure with a dry finger, and note made of the time which elapsed until it was hard throughout and free from stickiness. The temperature of 100° Fahr. was decided upon for the test, since this temperature could be readily maintained at any time desired, and would ensure uniformly favorable drying conditions.

It was found that a good grade of japan having the oil drying efficiency needed in our service, required slightly less than two hours thoroughly to dry the coating of oil under the above procedure, when five per cent. by weight of japan was mixed with 95 per cent. by weight of pure raw linseed oil, and this strength was adopted as standard for the test.

The "hardening test" was made in the same general method as the drying test, excepting that the oil was omitted. In other words the japan was flowed over the surface of a clean dry glass and placed in a vertical position in the oven at a temperature of 100° Fahr. and the time noted at which the coating was dry throughout upon firm quick pressure with a dry finger. In working out the details of this test we found it desirable to dilute the japan with an equal weight of turpentine, since some japans were so viscous that the correct time hardening could with difficulty be obtained owing to the thickness of the film. Also it was found that with a japan having sufficient hardening properties for our conditions of service, about twelve minutes were required to secure a hard coating. As has been stated above, a very small proportion of shellac or Kauri gum gave the condition desired, and we also found that if addition of rosin was made, the coating tended to remain in a brittle condition and to "dust" when scratched with a knife.

In the preparation of the japan it was of course, possible that sufficient time might not be given for thorough settling of any uncombined salts, or that the salts would not be thoroughly combined with the oil, and consequently we decided to make a diluting test by adding five cubic centimeters of the japan to 95 cubic cen-

timeters of turpentine, and it was specified that no precipitation nor settling must result, also, it was prescribed that in mixing the oil and japan for the drying test, no curdling must take place, and that the mixture make a clear, or nearly clear, solution. The mixture test with the oil indicates whether or not the japan is in too concentrated a condition to blend properly with the oil, and it also shows whether the material is over-cooked. If incorrectly made in either respect, a decided precipitation will result on mixing with raw linseed oil.

As the presence of rosin was questionably injurious it was specifically barred out, as was also mineral oil of any kind, for the same reason, and also owing to the possibility of causing fire through use of benzine. Specifications were then drawn up upon the lines indicated. They have been revised in minor details, and the present form is given below. These specifications have now been in force for several years, and have been found so effective that not a complaint regarding the quality of the japan has been heard since their adoption. Each shipment of japan, it is hardly necessary to add, is carefully tested immediately upon receipt, and the quality held to the specified standard. In case of rejection the freight charges are paid by the shipper.

As a matter of practice, the time of drying under our standard practice can be duplicated very closely by different persons, and the manufacturers have been enabled to keep a check upon the quality of their product by means of this simple test. In order to obtain exact results we have found it well to keep the bulb of the thermometer beside the oil film in the oven and to test the dryness of the film at about that point, since at times the difference in temperature between the bottom and the top of the glass effect a perceptible difference in the time of drying of different portions of the film.

The specifications in their present form are given below:

SPECIFICATIONS FOR JAPAN.

The material desired consists of a pure turpentine hardener and oil drier, conforming to the following:

1st. When equal parts by weight of the japan and of pure turpentine are thoroughly mixed and poured over a slab of glass, which is then placed nearly vertical at a temperature of 100° Fahrenheit, with

free access of air, but not exposed to draught, the coating shall be hard and dry, neither brittle nor sticky, in not exceeding twelve minutes.

2d. When thoroughly mixed with pure raw linseed oil at the ordinary temperature in proportions of 5 per cent. by weight of Japan to 95 per cent. by weight of raw linseed oil, no curdling shall result, nor any marked separation or settling on standing.

3d. When the above mixture is flowed over a slab of glass, which is then placed nearly vertical at a temperature of 100° Fahrenheit, with a free access of air, but not exposed to draught, the coating shall dry throughout, neither brittle nor sticky, in not exceeding two hours.

4th. When five cubic centimeters of the japan are poured into 95 cubic centimeters of pure turpentine at the ordinary temperature, and thoroughly shaken, a clear solution shall result, without residue, on standing one hour.

5th. After evaporation of the turpentine, the solid residue must be hard and tough and must not "dust" when scratched with a knife.

6th. Benzine or mineral oil of any kind will not be permitted.

Shipments which are not closely in accordance with these specifications, or which are not of uniform quality throughout, will be returned at the expense of the shipper.

DISCUSSION.

MR. S. S. VOORHEES.—Does Mr. Job find very much variation in the different linseed oils; that is, with the 5 per cent. of japan drier? **Mr. Voorhees.**

MR. ROBERT JOB.—We find a very decided difference in the different lots of linseed oil. We had a shipment a few days ago which was found to consist of about 60 per cent. of "foots" and 40 per cent. of linseed oil. We do not accept shipments of that kind, of course, and in making our tests we are careful to choose well-settled oil, one which has been proved pure by our previous tests. **Mr. Job.**

MR. VOORHEES.—I would ask if all commercially pure linseed oils show uniform time of drying when mixed with the same japan? **Mr. Voorhees.**

MR. JOB.—It is good practice to take a lot of oil which has not been allowed to oxidize for any considerable time. In other words, in making our regular tests we get a sample of oil from a fresh barrel and use that oil for several weeks, until it has gotten down possibly to one-third of the distance in the bottle. Then we get a fresh sample in order to avoid any possible change due to the oxidation of the oil. Under those conditions we find we can get quite closely agreeing results; that is to say, in making our tests we expect to find results by different operators agreeing possibly within about five minutes under the drying test, in about two hours at 100° Fahr. **Mr. Job.**

MR. FRANK P. CHEESEMAN.—Do you use the same japan in oxide as in carbon paints? **Mr. Cheeseman.**

MR. JOB.—Yes. It is quite light in color; and the japan, of course, is pretty strong; so that we shall have as small an amount as may be necessary to produce drying: that is, with 5 per cent. of the japan of the weight of oil we can get a dry coating in two hours at a temperature of 100° Fahr. **Mr. Job.**

MR. CHEESEMAN.—Do you change the proportion of driers in the different paints? Do you use the same quantity in oxide as in lead paints? **Mr. Cheeseman.**

Mr. Job. MR. JOB.—We do so pretty closely. It depends, of course, to a certain extent upon weather conditions; and that, of course, is left to a certain extent to the discretion of the painter. But ordinarily about 5 per cent. of the total amount—from 5 to 10 per cent.—is used.

Mr. Cheesman. MR. CHEESEMAN.—Do you use the same per cent. for wood as for iron?

Mr. Job. MR. JOB.—Practically the same.

RELATION BETWEEN SOME PHYSICAL PROPERTIES OF BITUMENS AND OILS.

By A. W. Dow.

There are, at the present day, a number of complex organic liquids of greater or less viscosity that are largely employed in manufacturing, or produced direct for the market. The materials I refer to are lubricating oils, oils and light tars for treating road surfaces, bitumens for waterproofing and impregnating felts and for use in the paving industry. These products are giving the analysts and engineers considerable trouble in devising tests that will be of practical value in their rating. The determination of the chemical constituents of these materials is practically useless as they have little or no bearing on their physical properties. Service tests are impracticable as they take too long and then it is impossible to have the same conditions in any two tests. There are, at present, a few physical tests that are made which are of some value but the information gained is far from what is desired to be ascertained. It is evident from this state of affairs that there must be one or more physical properties overlooked that play a most important part in the practical value of these materials and it is my purpose in this paper to demonstrate to you from results of tests and investigations on asphalts and like bitumens that the missing factor in our tests is probably that of surface tension of the materials under discussion. I will also discuss the possible physical conditions existing in these materials that give them their different properties in the hope that it may be an aid in the formulating of tests.

In my discussion on this subject I have chosen to class asphalts and other apparently solid bitumens under the heading of liquids, designating them "hyperviscous liquids", because they most closely resemble this class of matter in their physical properties. This is not at all novel to those familiar with modern physics as it has been demonstrated that there is practically no dividing line between solids and liquids and that the same physical

laws govern their properties. Tamman, a well-known authority, even goes so far as to call all solids that are not crystalline, and which, therefore, have no definite melting point, "super-cooled liquids".

The laboratory physical tests employed by the author in the examination of asphaltic bitumens are: susceptibility of the material to changes in temperature, the ductility, and the brittleness.

The susceptibility to change of temperature is ascertained by taking the penetration of the bituminous cement at different degrees of temperatures. In speaking here of penetration it is an arbitrary term that has been adopted in the asphalt industry. It refers to the distance a weighted needle will penetrate into a bituminous cement under a given weight in a given time. There have been one or two machines gotten out for making this penetration test but the one in most general use was devised by myself some years ago.

The ductility is determined by ascertaining the distance in centimeters that a briquette made of the material will draw out before breaking.

As the apparatus for determining the penetration and the method of making this test and also that for ductility have been described in print several times* I will not again describe them at the present.

The brittleness of a bitumen is determined by ascertaining the distance a weight of 25 grams must drop to break a prism of the material having a square section of 1 centimeter and a length of 10 centimeters resting on supports 8 centimeters apart. The test is usually made at the temperature of 0° C.

On comparing the data obtained on bitumens with these tests, it was noticed that a definite relation existed between the susceptibility to change in temperature, the ductility, and the brittleness.

In Table I will be found these tests on several bitumens. These are arranged in the order of their susceptibility to change

*The Report of the Inspector of Asphalt and Cements of the District of Columbia for the fiscal year ended June 30, 1904. *Proc. Am. Soc. Test. Mat.*, Volume III, 1903, p. 349.

in temperature, the most susceptible being at the top of the column. The numbers in the first columns to the left are the penetrations of several bitumens taken under various conditions indicated over each column. The next two columns to the right give the ductility of these materials taken at 0° and 25° C. In the last column to the right will be found the brittleness of these materials at 0° C.

In comparing the results in this table it is seen that in nearly every case a definite relation exists between these three physical properties; that is, the more susceptible to change in temperature, the more ductile and at the same time the more brittle is the

TABLE I.

Penetrations (No. 2 needle used in every test).	200 gs. 1 min. 0° C.	100 gs. 5 sec. 25 C.	50 gs. 5 sec. 38° C.	50 gs. 5 sec. 46° C.	Ductility. 0° C.	Ductility. 25° C.	Brittle 0° C.
Rosin and Mac. Oil	6	49	170	395	....	200	3
Coal Tar Pitch, old	3	38	130	310	....	200	..
Coal Tar Pitch, new	7	50	162	371	....	200	7
Reduced Cal. Oil	7	50	156	366	13.1	200	7
J. & B. Cal. Texas.....	10	52	134	338	11.3	200	..
Bermudez and Texas	12	51	114	265	6.3	52	..
Trinidad and E. Res.	13	50	110	257	5.6	37	8
Cuban and Texas	19	53	101	195	5.0	23	12
Hydroline and Texas	27	51	90	178	3.5	9	12
Maricaibo and Texas	26	53	80	135	3.1	9	52
Hydroline B. and Texas .	26	52	56	113	4.0	6	57

material. While all hyperviscous liquids do not appear to absolutely comply with this law, yet they follow it sufficiently close to enable one to make a close approximation of any two of the above properties from a knowledge of the other. I would also call to your attention that in the few cases where these hyperviscous liquids do not follow the general rule, that they closely resemble each other and it may be that with more perfect methods and materials free from foreign impurities, a still closer conformity may be expected.

Still another interesting relation is brought out and is exhibited in Table II. These results were obtained by taking the penetration of some of the materials represented in Table I with the same weight, and at the same temperature, but varying the time

interval. As in the other table they are arranged in the order of their susceptibility to change in temperature. These results show that the greater the ductility the greater the variation between the penetration taken at the different time intervals; that is, in testing two bitumens, one very ductile and the other lacking in ductility, let us suppose that they have the same penetration under 100 grams No. 2 needle, for 5 seconds at 25° C. If the penetration is now taken on these two samples at the same temperature with the same needle and weight but increasing the time to 1 minute, it is found that the more ductile one will be of considerable greater penetration than the less ductile one. To test this rule the same experiment was repeated at other temperatures and with different weights acting on the needle and

TABLE II.

Penetrations (No. 2 needle used in every test).	15° 200 gms.			15° 100 gms.		25° 100 gms.	
	5 sec.	1 min.	5 min.	5 sec.	5 min.	5 sec.	1 min.
Rosin and Mac. Oil	12	72	165	18	105	52	190
Reduced Cal.	20	62	165	9	104	53	156
J. & B. No. 2 and Cal. ..	21	63	166	7	103	53	155
Hyd. B. and Texas	39	74	112	27	73	55	82
Bermudez and Texas	24	67	144	10	94	53	129

the same relations were found to exist. Three other physical properties also appear to be related to those just mentioned. *First:* The more ductile bitumens are the more fluid; that is, of two materials both of the same penetration when tested at 25° F., the one that is the more ductile will flow the more readily into an aperture, or more readily flatten down of its own weight. In fact a very hard California oil residue will have considerably more flow to it than a soft hydroline B. *Second:* That of two bitumens having the same consistency by penetration at 25° C., the one that is more ductile will the more readily penetrate into fibrous material, such as felt and paper, when the bitumen is in a molten condition. This is an important factor in the roofing and water-proofing industry. *Third:* Relates to the penetrability of oils into road surfaces in the construction of oiled or tarred roads. I have noticed it to be invariably the case that of two oils of the same viscosity, the one which, on evaporation gives a residue

that is the more susceptible to change in temperature, is the oil which will the more readily penetrate into the road surfaces.

Having established the above relations between the various asphaltic bitumens I turned my attention to the testing of oils, applying to them the viscosity test which I considered the nearest equivalent to the penetration tests, and fully expected to find the same relations between results obtained under different conditions. As a difference had been noted in the penetrability of the two oils into road surfaces, as spoken of above, it was believed marked differences would be observed in the viscosity of these two oils, when taken at different temperatures. To test this two heavy oils were selected, having the same viscosity on a Doolittle viscometer at 45° F., the one oil had the property of being readily absorbed into the surface of the road, while the other had not. The viscosity was determined at every 10° C. from 45° to 75° C. I was much surprised to find that the tests on these oils ran parallel with each other at every temperature. Other oils were experimented on, but no great variation could be detected in the viscosity at different temperatures with the exception of one paraffine oil which possibly contained scale paraffine melting at 55° C., giving a rather sudden jump in viscosity.

Tests were then made with a viscometer of my own design which consists of a cylinder 2 centimeters in diameter of equal bore throughout, fitted with a plunger 1 millimeter less in diameter. This plunger is used in the frame of the penetration machine in place of the needle, and the distance the plunger sinks under a weight of 50 grams in 5 seconds is taken as the viscosity of the oil. The viscosity by this apparatus can be compared to that obtained on the regular pipette viscometer. The results obtained at different temperatures did not materially differ from those given by the Doolittle viscometer. From these results it is evident that the penetration test does not entirely, if at all, correspond to the viscosity test, and the question naturally arises what other physical laws govern this test.

This question and the relative physical properties of the different asphaltic bitumens, have been the occasion of considerable speculation on my part in the hope that they might reveal something as to the physical constitution of these bodies. I am inclined to believe, for several reasons, that they indicate

the degree of solution of the various compounds composing these materials in each other. That is, the more complete the solution of the compounds in each other the more susceptible to temperature and the more ductile, or in other words, it would appear that as you progress from the ductile materials toward the non-ductile that the solutions of the various hydrocarbons in each other become more incomplete, resembling in some ways colloidal solutions and in some extreme cases even a state of emulsion. And I might here say that it has lately been shown that emulsions resemble colloidal solutions in many ways. This theory is still further strengthened by the failure of the viscosity test to coincide with the penetration test and points strongly to the conclusion that the former test is more an indication of surface tension than of viscosity. I believe it also explains the relation existing between the difference in penetration for various time intervals and the properties of ductility and fluidity and the susceptibility to changes in temperature.

Theorising on the composition of these materials, let us suppose that in Fig. 1 A and B are sections through two samples of materials after the needle has penetrated for 5 seconds, these materials both have the same penetration for this time interval. Fig. A is the ductile material that readily loses its shape or flows. Fig. B is the non-ductile and non-fluid material such as hydroline B. According to the theory sample A is composed of two liquids, W and X, the latter being in a colloid state in W. As A, is nearer to a true solution there is but little of colloid X present and the rigidity of A is entirely due to its external surface tension, that is a high surface tension of liquid W. Sample B is composed of two liquids, Y and Z, the latter being in a colloid condition in Y. The material B owes its rigidity to the surface tension of the particles of the colloid liquid Z, and is but little dependent on the external surface tension of liquid Y, which may be of very low surface tension. In other words, this liquid might be likened to a sponge, liquid Z being the fibers and Y a light low surface tension liquid held in the pores. It is seen in sample A that the first penetration of the needle into this material causes a large depression surrounding the needle. In the case of B there is little or no depression. It is evident from this that considerable of the work of the needle in penetrating in the case of A is in

overcoming the surface tension of liquid W, while in B the surface tension being low the needle meets with little or no resistance, but, as it proceeds, is retarded by the internal surface tension of the particles Z. If now, the needle is allowed to penetrate for a longer time it is evident that it will penetrate further into A than into B because of it continually meeting resistance from the internal tension of particles Z. This is further brought out by the shape of the surface after the penetration of the needle, for though it has penetrated to an equal depth into both samples in the first 5 seconds, A is proved to be much softer than B, as it has not only to make a penetration but carry with it the large mass of material which adhered to the point of the needle.

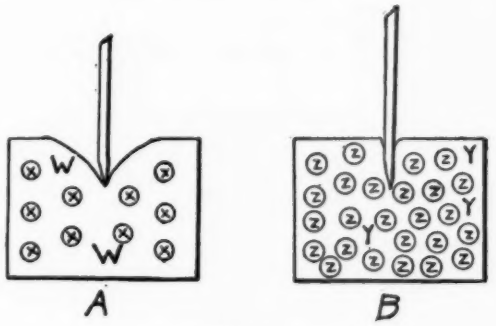


FIG. 1.

With two asphaltic bitumens having this internal structure it is easily understood why A loses its shape, or, in other words, is more fluid than B, even though to the feeling or the penetration A may be harder than B.

If we now apply this theory to lubricating oils I believe it can be readily appreciated why some oils of high viscosity are incapable of keeping bearing surface apart and are, at the same time, poor lubricants, while other oils of less viscosity act so well both in keeping bearings apart and in lubricating. If we now suppose two oils to be represented by A and B the former would represent an oil largely dependent on external surface tension for its viscosity while B would represent an oil with a low external surface tension but dependent on its internal surface tension for its viscosity.

Liquid A having little or no colloid present in it would readily be squeezed out between two bearing surfaces and at the same time having a high external surface tension would act as a retarding agent between two bearing surfaces. In the case of liquid B it would be just the reverse and the bearing surface would be kept apart by the colloid condition, and liquid Y, having a low surface tension, would act as a good lubricant. This might explain why soaps are used as lubricants because of their colloid conditions and also explains why the addition of lard oil to a mineral oil improves its lubricating properties for heavy machinery, because the lard oil enters into a colloid condition in the mineral oil.

If this theory as to the physical constitution of these more or less viscous liquids is correct, as it is reasonable from the above to suppose, it can be readily appreciated what an important factor the examination of the surface tension of oils would play not only in the industry above mentioned but in numerous others. For example, the character of paint is largely dependent on these physical properties, that is, of two paints the one that has an oil medium approaching closer to what I term a true solution, the closer will the pigment be brought in contact with the surface of the material covered, which I believe is of great importance in paint acting as a preservative.

There has been little or no work done on this line with these complicated liquids and in fact our knowledge of surface tension in any line is very limited. If it were possible to work out a practical way of determining external surface tension and the internal tension of the surface of the colloids it could not help but result in great practical value as a means of examining the physical properties of these materials, and would likely prove of great commercial value. It is to be hoped that some physical chemist who is more used to investigating than the author, may take this subject up and it may even seem advisable for this Society to endeavor to have the Bureau of Standards, Washington, D. C., take up the investigation of this kind with a view of standardizing a method for the examination of lubricant oils and other complex liquids.

DISCUSSION.

Mr. C. N. Forrest.—I should like to make a few remarks in connection with Table I presented by Mr. Dow showing the penetration of various bituminous substances at different temperatures, and to add, perhaps, a little to that table as an aid to more intelligent interpretation of the results. Mr. Forrest.

Mr. Dow in his later remarks referred to the behavior of oils containing paraffine in his viscosity tests, showing that those oils rich in paraffine are more susceptible to temperature changes; and we all know that paraffine is a material that is affected very readily by temperature changes; that is, it becomes very fluid at elevated temperatures and is solid and very brittle at low temperatures. In this connection, therefore, it would be particularly interesting to know the character of the oil that was used in reducing the various hard asphalts to the consistency that they were brought to in order to make the penetrations; the penetrations given in the table are not directly comparable in that some asphalts have been fluxed with one oil and some with another. Even the term Texas oil is not entirely definite; as we have oils from different parts of Texas possessing different characteristics. The Corsicana oils are particularly rich in paraffine; while among the asphaltic oils from the other fields some contain a greater amount of paraffine than others and on this account it would be very interesting to know the amount of paraffine present in the various fluxes employed. It is not surprising, therefore, in the case of the Trinidad asphalt, which has been fluxed with an eastern residuum particularly rich in paraffine, running perhaps as high as 7 or 8 per cent. paraffine scale, that that cement, as shown, should be more brittle at a low temperature, and affected to a little greater extent at the higher temperature, than some of the others, I wish to say, therefore, that in order to have entirely comparable results, the hard asphalts should all have been fluxed with the same oil; and it would be interesting to know, even in those asphalts which have been described as being fluxed with Texas oil, if the Texas oil all came from the

Mr. Forrest. same region, and if the amount of paraffine varied in the different fluxes.

Mr. Dow. MR. A. W. DOW.—I think Mr. Forrest is mistaken about that; because I find that when an oil is mixed with an asphalt that the oil loses its characteristics. In fact, Trinidad asphalt fluxed with a California oil is more susceptible to changes in temperature than when fluxed with eastern paraffine oil. The character of the oil or asphalt has nothing at all to do with the physical properties of the resulting mixtures; they depend on what condition or what solution the oil enters into with the asphalt. If you take an asphalt which is easily soluble in an oil, it will make a more ductile material, and vice versa; the eastern residuum oils are not as good solvents as the California oils. I regret that I have not any tables here to show that, but the Trinidad asphalt fluxed with a California oil would be more susceptible than with the eastern residuum, as I said. Referring to Table I for instance, so-called Maracaibo asphalt, if that was fluxed with a California oil instead of Texas oil it would bring it up into the class with the Cuban asphalt; and yet the Texas oil contains more paraffine than the California; from this it is seen that the paraffine really plays little or no part in the behavior of those materials.

Mr. Forrest. MR. FORREST.—The characteristics which I mentioned, are more plainly shown in the Texas fluxes and the eastern residuums; and our experience with those two oils is somewhat at variance with Mr. Dow's remarks. The fact that the California oil is used to a very limited extent for the fluxing of such asphalts as Bermudez and Maracaibo or Trinidad, perhaps, is responsible for my not being as thoroughly posted in regard to that particular oil as Mr. Dow; but with the Texas oil and the eastern residuum oils, our experience has been that those cements—that is, asphalt cements fluxed with an eastern residuum containing a considerable amount of paraffine (7 to 10 per cent. perhaps)—are very much more susceptible to temperature changes than the same cements made with a Texas oil.

Mr. Dow. MR. DOW (referring to Table I).—Hydroline and Texas is the residuum of Texas oil, and contains about three or four per cent. of scale paraffine—while this reduced California oil contains little or no paraffine, yet the reduced California oil, being a truer solution than the Texas residue, is the more susceptible to changes

in temperature, even though it does not contain paraffine. It is shown by this that the paraffine has no influence on the physical properties. **Mr. Dow.**

MR. FORREST.—I do not wish to prolong the argument; but Mr. Dow is entirely right in saying the California oils are very susceptible to temperature changes; that we know; and we also know that residual pitch prepared from California oil is much more brittle at low temperatures and fluid at high temperatures, than residual pitch prepared from Texas oils. On account of that fact it is not surprising that he should find a difference in penetration in the cements prepared with eastern residuum oils and the California oils; but I wanted to emphasize the relation between the Texas oils and the eastern residuum oils, not going into the California oil proposition at all, because, as I say, that is a material that does not enter into the paving question very largely in the East, or in the Middle West, as a flux for hard bitumens, and by hard bitumens I mean particularly Bermudez, Trinidad and Maracaibo. **Mr. Forrest.**

MR. S. S. VOORHEES.—In Mr. Dow's theory of incomplete solutions as shown in Figs. A and B, the penetration of the needle in B should be affected even from the start, should it not, by the crowding apart of the colloids Y; and the penetration would therefore not be the breaking of the surface tension of Y exactly, but also the effect of the colloids Z over the whole surface of Y affected. **Mr. Voorhees.**

MR. DOW.—Yes, it is; and, as I explained, A is really much softer than B, for that very reason the colloids Z hold it up like a sponge. **Mr. Dow.**

MR. VOORHEES.—Should not that retard the penetration on that account? **Mr. Voorhees.**

MR. DOW.—Yes, it does. These two materials were chosen with the same degree of penetration at 5 seconds under 100 gms. at 25° C., and when the penetration is made for a longer time the retarding of the needle is plainly seen by the results in the last column of Table II. **Mr. Dow.**

MR. E. W. DE KNIGHT.—I should like to inquire the reason for combining the resin oil and machine oil. **Mr. De Knight.**

MR. DOW.—The resin is what I consider a good solvent for the bitumen oils; that is, it enters into complete solution with bitumens; and as paraffine is not a good solvent, I combine the **Mr. Dow.**

Mr. Dow. resin with a paraffine machine oil to show that even resin will make a ductile material that way; it was made simply as an experimental sample to illustrate the point that the greater the ductility, the greater the susceptibility to change in temperature.

Mr. De Knight. MR. DE KNIGHT.—I should like to ask whether Mr. Dow recommends resin for waterproofing materials?

Mr. Dow. MR. DOW.—No. I might repeat what I said in other words: this paper is an entirely theoretical consideration of the subject. I did not mean this sample to represent anything practical, at all; but merely to illustrate the point I was trying to bring out. I have never tried the waterproofing qualities of resin with machine oil.

Mr. De Knight. MR. DE KNIGHT.—Is it a good thing to put resin in any waterproofing material? Why was there no resin in any of the other materials illustrated in the sketch?

Mr. Dow. MR. DOW.—There is no resin in any of the other materials; and I might say, as is well-known to roofing and bitumen men, that when they want to increase the ductibility of a bitumen they add resin.

THE PROXIMATE COMPOSITION AND PHYSICAL STRUCTURE OF TRINIDAD ASPHALT, WITH SPECIAL REFERENCE TO THE BEHAVIOR OF MIXTURES OF BITUMEN AND FINE MINERAL MATTER.

By Clifford Richardson.

The vast deposit of native bitumen, extending over an area of more than one hundred acres and to a depth of over one hundred and thirty-five feet, obtained in the so-called pitch lake, which occupies the basin of an old mud spring in the Island of Trinidad, has been known for some time to be extremely uniform in its proximate composition, consisting of a mixture or emulsion of bitumen, a thermal water, free carbon dioxide and hydrogen sulphide, and mineral matter, with an undetermined residue, which has been denoted "organic matter, not bitumen." The composition of the "pitch" as taken freshly from the lake, according to the methods of analysis hitherto generally employed, has been stated to be as follows:

Average of 30 Analyses.

	Per cent.
Water and gas, loss on drying at 100° C.	29.0
Bitumen soluble in cold carbon disulphide	39.0
Mineral residue after ignition	25.2
Undetermined matter by difference, "organic matter not bitumen."	6.8
	100.0

Industrially the crude pitch is submitted to a process of so-called refining, which consists of heating it to a temperature of not over 160° C., for the purpose of driving off the water present and obtaining a dry and compact bitumen. In this process nothing is removed except matter volatile at this temperature, so that the product may be regarded merely as dried pitch. In this

form it has the following average composition when examined in the same manner as the original material:

AVERAGE OF 15 ANALYSES.

	Per cent.
Bitumen soluble in cold carbon disulphide	56.5
Mineral residue after ignition	36.5
Undetermined, by difference	7.0
	100.0

If the composition of the crude pitch is calculated to a water and gas free basis, the bitumen, mineral, and undetermined matter will be found to be present in the following proportions:

	Per cent.
Bitumen	55.0
Mineral	35.5
Undetermined	9.5
	100.0

From the preceding data it appears that there is less undetermined matter in the refined asphalt than in the original pitch. It is evident, on reflection, that the figures obtained by the methods of analysis employed, do not accurately represent the actual composition of the substance. The percentage of bitumen represents the amount soluble in cold carbon disulphide and may be too low. A hot solvent or a better one might remove more. There is reason to believe, since the mineral matter consists to a considerable extent of clay, that this, or even the other mineral matter, might absorb or adsorp bitumen in a way which would prevent its removal by solvents. The mineral residue after ignition may be too low, owing to the volatilization of the water of hydration of the clay and of some of the more volatile inorganic matter such as the alkalies and the sulphuric acid in combination with the ferrous iron in the thermal water. All these errors would be cumulative in the undetermined matter by difference and thus make the percentage assigned to this material much too high, even if it is not found to consist entirely of such substances which are in no sense organic matter not bitumen.

With a view of determining with some certainty what the

character of the substances are which go to make up that portion of the refined asphalt which has been heretofore regarded as "organic matter not bitumen" the following investigations have been carried out in the writer's laboratory.

Water and Gas.—If a weighed amount of crude Trinidad asphalt, immediately after being taken from the deposit, is ground to a fine powder and exposed to the air for twenty-four hours, it will lose about 29.0 per cent. of water and a small additional amount on further exposure in vacuuo over sulphuric acid, this latter small amount being very probably water of crystallization of the salts which are present. The total loss averages 29 per cent., with but very small variation, in the fresh pitch taken several inches below the surface, although on exposure to the air for some time a very considerable proportion of this amount may be lost, as in the case of storage of the crude material.

At the same time with the water the gas which it contains in solution, consisting of a mixture of carbon dioxide and hydrogen sulphide, is lost. Its percentage must be extremely small by weight.

Having determined the average amount of water in the fresh pitch with some degree of accuracy it will be convenient to conduct the further investigation of the pitch on the dried or refined material.

Mineral Matter.—The residue of mineral matter obtained on the ignition of refined Trinidad asphalt in a muffle averages, as the result of fifteen determinations of representative samples, 36.5 per cent., corresponding to 25.9 per cent. in the original crude material, with extremes of 36.0 and 36.8 per cent. As this ignition has taken place at a temperature approaching 800° C. there is every reason to believe that considerable organic matter has been volatilized, as is often found to be the case in the preparation of the ash of vegetable material. In the latter case the addition of tricalcium phosphate prevents such loss and it seemed that this mode of procedure might be applicable to the asphalt. When the latter was ignited in the presence of the phosphate a residue greater by 2 per cent. was obtained, 38.5 per cent., and one which more correctly represents the percentage of anhydrous inorganic matter present in the asphalt, showing that 2 per

cent. is volatilized in the ordinary course of ignition, thus accounting for this amount of the "undetermined matter."

The mineral matter on examination is found by elutriation to consist to a large extent, 30 to 40 per cent., of clay and, of course, its water of hydration, which may be properly regarded as a part of the mineral matter originally present, is lost on ignition. If the residue after the extraction of the asphalt with solvents is heated to a temperature of 340° C. it loses from 4 to 6 per cent., the determination at such a temperature, of course, not being one capable of being made with great accuracy. A certain amount of this loss is plainly due to the volatilization or destruction of bitumen held by the clay present, as shown by its condensation on the side of a glass tube in which the heating is conducted, but as this amount, as will appear later, cannot exceed 1 per cent., the loss due to the presence of water in the clay must reach at least 4.5 per cent. The total loss on ignition, of bitumen and water in the clay must, however, amount to about 5 per cent. and be included in the "undetermined matter." When this per cent. is added to the 2 per cent. of inorganic matter volatilized at 800° C. the entire percentage of undetermined matter obtained by the usual method of analysis is accounted for, as it appears that Trinidad asphalt really contains practically no organic matter not bitumen.

In order to determine whether this assumption is correct, analyses have been made of mixtures of an extremely pure bitumen, gilsonite, with clay and other fine inorganic materials, the mixture being prepared by melting the bitumen and stirring the clay or other mineral matter into it, the stirring being kept up during cooling, and the cold brittle mixture being then ground to a fine powder in order to obtain a uniform material for analysis. The results of an examination of such mixtures by the routine methods are as follows:

	Bitumen, soluble in carbon disulphide.	Mineral residue on ignition.	Undetermined.
	Per cent.	Per cent.	Per cent.
Fullers earth—air dried	62.3	28.8	8.9
Fullers earth—ignited	59.7	34.1	6.2
Brick clay—air dried	72.3	22.9	4.8
Brick clay—ignited	77.9	17.9	4.2
Portland cement—ignited	82.6	15.8	1.6
Trinidad mineral residue—ignited	64.4	34.3	1.3

It appears from the preceding results that all the artificial mixtures of bitumen and fine mineral matter apparently contain as the result of the analyses a certain amount of undetermined matter or organic matter not bitumen, although from the nature of these mixtures nothing of this kind can be present. The amount varies from 8.9 per cent. in the case of the unignited Fullers earth, to 1.3 per cent. for the ignited mineral residue of Trinidad asphalt. The larger percentage is due to the presence of water of hydration in the Fullers earth, while the smaller percentage shows that the mineral matter in Trinidad refined asphalt is capable of retaining 1.3 per cent. of bitumen, either by absorption, adsorption, or both. Our assumptions in regard to the true composition of Trinidad asphalt are, therefore, correct and its actual composition should be stated as follows:

	Crude Trinidad Asphalt. Per cent.	Refined Trinidad Asphalt. Per cent.
Water and gas	29.0	..
Bitumen soluble in cold carbon disulphide	39.0	56.5
Bitumen retained by mineral matter	.3	.3
Mineral matter, on ignition with tricalcium phosphate	27.2	38.5
Water of hydration, clay, and silicates	3.3	4.2
	98.8	99.5

In neither case is it possible for the occurrence of that percentage of "organic matter not bitumen" which has heretofore been attributed to Trinidad asphalt.

Bitumen.—In consequence of the preceding results it is of interest to study to some further extent the behavior of bitumen towards clay and other extremely finely divided inorganic particles.

Behavior of Bitumen with Clay and finely divided Mineral Matter.—It is well known that clay has the power of absorbing bases and dyes from their solutions and holding them so firmly that they cannot be entirely removed by solvents.*

*Cushman, Bulletin No. 92, Bureau of Chemistry, U. S. Dept. of Agriculture, page 16. Cameron & Bell, Bulletin No. 30, Bureau of Soils, U. S. Dept. of Agriculture pages 52–61.

In this connection the behavior of solutions of bitumen toward clay and other fine mineral matter has been investigated. For this purpose a weighed amount of air-dried white clay from Berkshire County, Massachusetts, was spread on the asbestos felt of a Gooch crucible and a 10 per cent. solution of an extremely pure bitumen, gilsonite, in purified carbon disulphide was poured upon it and allowed to remain in contact with it for fifteen hours. The solution was then removed by suction and the clay was washed with the same solvent until the latter came through colorless. The same experiment was conducted with a brick clay from New Jersey, and with Fullers earth from Florida.

On drying the white clay and breaking it open it was found to be strongly colored by the absorbed bitumen which had not been removed by the solvent. The amount of bitumen retained by the different clays was found to be:

White clay from Massachusetts	1.28	1.03
Brick clay from New Jersey	1.24	1.38
Fullers earth from Florida	8.94	

It is evident that the different clays have different capacities for absorbing bitumen and it is not surprising to learn that Fullers earth retains the largest percentage, since the use of this material has been extremely successful for the purpose of clearing distillates of petroleum.

It seemed possible that an air-dried clay, owing to the presence of hygroscopic moisture which it might hold, might not absorb as much bitumen as one which had been dried at a temperature above the boiling point of water. In order to determine this the experiment was repeated with the brick clay from New Jersey after drying at 120° C. The results obtained are as follows:

Brick clay from New Jersey	1.07	1.28

There is but a trifling difference in the amount of bitumen absorbed by the air-dried clay and the dried clay.

In the same way it seemed possible that an ignited clay might not have as large powers of absorption as air-dried or dried clay. For the purpose of determining this ignited Fullers earth

and the mineral residue from the ignition of refined Trinidad asphalt were subjected to the action of a bitumen solution and the amount of bitumen which was absorbed in each instance and could not be removed by solvents on continued washing was found to be:

	Per cent.
Fullers earth	5.8
Mineral residue from Trinidad asphalt	.89

The Fullers earth, it is found, does not present the same absorptive powers after ignition and it may, therefore, be assumed that the mineral residue from Trinidad asphalt, in the condition in which it exists originally in the crude or refined asphalt, would absorb more than nine-tenths of one per cent., which the ignited residue does.

It is evident, therefore, that the amount of bitumen extracted by a solvent from any mixture of that substance with a material containing clay does not represent all that is present in the mixture, and that, in the course of an analysis made according to the customary methods, the amount of bitumen would be included in the percentage of undetermined material. The amount, will, of course, depend upon the nature and proportion of the clay present.

With a view of determining the behavior of solutions of bitumens of various kinds towards clay, Fullers earth, ground limestone, silica dust, and Portland cement, 90 per cent. or more of which pass a screen of 200 meshes to the linear inch, when such solutions are passed through a column of these materials closely packed together in a glass tube, a number of experiments have been made. For this purpose glass tubes two centimeters in diameter and 150 centimeters long were filled for a distance of 50 centimeters with the mineral powder under experiment.

Carbon disulphide containing $\frac{1}{10}$ per cent. gilsonite in solution is completely decolorized in passing through a column of Fullers earth, of the length mentioned. The solvent comes through quite pure. Eventually the solution becomes slightly colored and finally brown, but on evaporation of the first portion of the colored solution the residue is found to consist of bitumen in the form of malthenes or the softer hydrocarbons of gilsonite,

showing that there has been a selective absorption, similar to that which has been observed in the case of passing crude petroleums through clay. A 2.5 per cent. solution treated in the same way comes through slightly colored from the beginning and soon contains the unchanged gilsonite.

After removing the Fullers earth from the tube and drying the same it is found to be colored a very deep brown and all of this color could not be washed from it by means of solvents. The action of Fullers earth on gilsonite is strongly absorptive and selective.

With finely powdered limestone a similar result is obtained but the amount of colorless solvent which passes is much less than in the case of Fullers earth.

In both the above cases absorption may be considered as the principal cause of the action of the fine mineral matter. In order to determine whether this was the sole cause tubes were filled with ground silica and with Portland cement, neither of which could possibly have any absorptive action. In neither of these cases did the solvent come through colorless at any time, but at first was a light straw color, quite different from that of the original solution which was jet black, and the bitumen in solution was of a soft nature. After removal of the mineral matter from the tubes it could be washed quite free from bitumen with the solvent, showing that there had been no actual absorption. From this it must be assumed that absorption plays a large part in the retention of bitumen by mineral matter.

Similar experiments were carried on, using Trinidad refined asphalt instead of gilsonite. With this material the solutions were in every case colored, but contained in solution only the lighter hydrocarbons of the asphalt, and the fact that powders could not remove the bitumen entirely in the first portions passing is due to the presence of hydrocarbons of much lower molecular weight, as low as C_{13} H_{26}, in the asphalt than in the gilsonite.

The behavior of bitumen with these fine materials is of great interest from an industrial point of view as explaining the strong adhesion of bitumen to the mineral aggregate composing the major portion of an asphalt wearing surface.

Physical Structure of Trinidad Asphalt.—Having become

acquainted with the proximate composition of the refined Trinidad asphalt it is of interest to study, and determine if possible, the manner in which the components have become combined in the crude asphalt and the reason for their existing in such very definite proportions in all parts of the deposit. The conclusion was originally drawn that the mixture of water, mineral matter, and bitumen existed in the form of a mere emulsion, but the observation that when the crude asphalt was shaken with an excess of carbon disulphide no water rose to the surface showed at once that this was not the case, but that the water must be held by the clay and not in emulsion with the hydrocarbons. That this is so can be readily proved by shaking a paste of clay or fine sand and water with carbon disulphide, when, as would be expected, the water does not rise to the surface of the carbon disulphide. A determination was then made of the amount of water which a residual clay such as is found in Trinidad asphalt would hold, either chemically combined, by adsorption, absorption, or in the voids between the particles.

When it was placed upon the felt of a Gooch crucible, moistened with water, and any excess allowed to pass off through the felt, the amount retained was found to be 136 per cent. of the original weight of the clay. When the water in the voids was removed as far as possible with a vacuum pump that retained amounted to 89 per cent. On placing the moist clay over sulphuric acid in vacuo very nearly the entire amount of water which was present in the clay was removed. At higher temperatures about 5 per cent of adsorbed water was lost, while on ignition 8 per cent was found to be in combination, or perhaps partly adsorbed. It is evident that clay has a great capacity for water and if we observe the relation between water and residual mineral matter in the crude Trinidad asphalt, 29 per cent. of water and 30.6 per cent. of mineral matter, it is readily seen that the amount of mineral matter present is quite capable of absorbing and holding the water present. That clay actually absorbs the water under these conditions is not unexpected since it is frequently used for the purpose of removing water from oils and clarifying them. We may assume, therefore, that the definite relations of water and residual mineral matter in the asphalt are due to some definite equilibrium between the two materials, depending upon the

capacity of the mineral matter for water. The mixture of the two may be regarded as the mud of the original spring.

To account for the definite ratio of mud and bitumen found in the crude asphalt it does not seem out of place to assume that a similar physical equilibrium occurs. The mud must be able to take up and hold a definite amount of bitumen and no more, although we cannot at present explain why the relations should always be about 60 per cent. of mud to 40 per cent. of bitumen.

Artificial mixtures have been made of clay, water, and pure bitumen, in which these substances are present in the same relation as in the crude asphalt. If the water and clay are first mixed the bitumen can be readily combined with the mud, but if the bitumen and clay are first mixed and heated to the softening point of the bitumen, a mixture cannot be made, as the clay absorbs the bitumen and prevents the entrance of water, although under the high temperatures and pressure which undoubtedly exist where the crude material is formed, the conditions would be somewhat different. The preceding fact would appear to be in confirmation of the conclusion that the mud must have been formed first and the bitumen afterwards combined with it.

It is of interest to note that the artificial mixtures, which have just been described, lose their water as rapidly when exposed to the air as does the crude Trinidad asphalt, a mixture containing 29.5 per cent., having lost 29 per cent. in the course of 24 hours.

The preceding problem is an interesting one and is worthy of further investigation. It has been definitely settled from the results thus far obtained that Trinidad asphalt does not contain the amount of "organic matter not bitumen" that has been attributed to it and probably only a minute amount derived from grass or other vegetable growths.

DISCUSSION

Mr. A. W. Dow.—I want only to second one thing that Mr. Richardson stated, and that is about the clays and similar materials absorbing bitumen. It is very well known that Fullers earth is used in the oil industry to absorb the coloring matter out of oils; and a very interesting result of material like clay absorbing bitumen was developed last year, while the asphalt committee were getting up a standard method for the determination of bitumen. Dr. Cushman, of the Road Material Laboratory, suggested the use of plaster of Paris as a filtering medium. When one first starts in passing a bisulphide solution of bitumen through the plaster of Paris as much as 40 mgms. of the bitumen would be absorbed. The filter was an ordinary small Gouch crucible with about $\frac{1}{8}$ inch of plaster of Paris in the bottom Mr. Dow.

One thing in the paper I can not agree with. I understood the author to say that because he shook up the crude Trinidad asphalt with bisulphide, and as the water would not separate out, he inferred from this that it was not an emulsion. I merely want to state that it is no proof that an emulsion does not exist between the asphalt and the water because the latter does not separate out when the crude asphalt is shaken up with carbon bisulphide.

I have found many emulsions of oil and water that can not be separated by shaking with carbon bisulphide. My first experience of this kind was in studying the composition of a bright yellow slime that is deposited on any object immediately over an asphalt refining tank or kettle, by the condensation of the steam and light oils driven off from the asphalt. On shaking this slime up in carbon bisulphide I was much surprised to find that it was practically insoluble even on heating. On treating it with alcohol, however, there was an immediate and complete separation of the oil and water. This phenomena is readily explained when we consider that in this emulsion the water being largely in excess, each oil globule was completely surrounded by water so that the

Mr. Dow. carbon bisulphide could not reach it, but on adding the alcohol it combined with the water lowering its surface tension to such an extent as to destroy the emulsion.

Mr. Forrest. MR. C. N. FORREST.—That is also the case in shaking a mixture of clay and water with bisulphide of carbon. The water does not separate in that case; but the addition of alcohol does cause the water to rise to the surface of the carbon bisulphide.

Mr. Voorhees. MR. S. S. VOORHEES.—I should like to ask Mr. Forrest if in the extraction of this absorbed bitumen from the Fullers' earth, he could not have removed it all by using hot instead of cold carbon bisulphide?

Mr. Forrest. MR. FORREST.—We did not try that. We used cold carbon bisulphide; because that is the universal solvent for bitumen.

Mr. Voorhees. MR. VOORHEES.—I had in mind whether it would not be possible to determine whether there was any organic matter not soluble in carbon bisulphide by means of direct combustion after the bitumen had been extracted with hot carbon bisulphide or some other solvent.

Mr. Forrest. MR. FORREST.—These are all questions which I am glad are being brought out in discussion; and I will say they will undoubtedly be considered by Mr. Richardson and he may reply to them in writing, so that it will appear in the published Proceedings. As this is Mr. Richardson's paper I should not like to put words in his mouth in carrying on the discussion on his part.

Mr. Voorhees. MR. VOORHEES.—I am simply looking at it from the standpoint of an analyst to get means for the determination. If carbon is there as carbonates, of course they can be removed by the action of hydrochloric acid; and bitumen, if present in a soluble form, could be dissolved out in a suitable solvent. Then organic matter could be determined by direct combustion and absorption by CO_2.

Mr. Forrest. MR. FORREST.—In passing the solutions through Fullers' earth the bitumen was all originally soluble in carbon bisulphide; and the matter that was retained by the finely divided mineral substances was in a form capable of being dissolved by cold carbon bisulphide; but, as a matter of fact, we were not able to wash the mineral matter clear with the same solvent that the bitumen was originally dissolved in. The organic matter was exactly the same in both cases.

MR. E. W. DE KNIGHT.—Has not the clay and bitumen of an asphalt pavement something to do with the absorption of water by the usual asphalt streets or pavement? Mr. De Knight.

MR. FORREST.—No, not at all; because a perfect asphalt pavement does not absorb water; and I do not think it is customary to use clay as a filler in an asphalt pavement, aside from the clay which might be naturally combined with asphalt. Clay is such a light material that it is difficult to handle it, although it may be a very desirable filler. It has such a low volume weight that it is a very difficult matter to introduce it into a hot mixture. Mr. Forrest.

MR. A. B. HARRISON.—It has been my experience that in the mixture of a mastic for street paving or other purposes, by using as nearly as possible a pure bitumen relatively the same results are obtained as in mixing concrete. If the sand contains loam in concrete mixture it gives trouble, and for the reason, I think that it absorbs the cement, and the loam itself has no strength. Muddy or clay matter in a bitumen adds no strength to it at all; in fact, is detrimental to the mastic in exact proportion to the percentage contained; whereas, if the sand that the bitumen is mixed with, is clean, the more pure the bitumen is, the less bitumen is required to give you efficient results, making the mastic not only waterproof, but strong and lasting, there being no substance present to cause disintegration. Mr. Harrison.

MR. DE KNIGHT.—One more question. When we refine asphalt, it is for the purpose of getting out of it certain earthy materials. When we make a mastic, we throw back into the refined material not only sand and lime, but earth of various kinds. Is it not wrong to make a mastic or any waterproofing material in that manner? Mr. De Knight.

MR. FORREST.—The refining of asphalt merely consists of removing the moisture. No attempt is made to remove the mineral matter that might be combined with it; and in most cases at least, the mineral matter which does occur naturally combined with the asphalt is in a particularly desirable form. It is extremely finely divided, and in that state is very valuable for use as a filler in the pavement; and, answering the previous speaker, I would say that one very important requirement of sand for the construction of asphalt pavements is that it shall be clean, that it shall contain no loam; not that the loam is particularly injurious to the asphalt Mr. Forrest.

Mr. Forrest. as such, but a loamy sand is a dirty sand; the loam adheres to the grains of sand, and in that position prevents the adhesion of the cement to the sand. No successful asphalt pavement can be made without the use of a finely divided mineral matter. Its chemical nature is not so important as its physical nature. The ordinary requirement is that at least 70 or 80 per cent. of this finely divided mineral matter shall pass a 200-mesh screen; but our idea of a mineral matter for use as filler is even more refined than that, and we require that at least 60 per cent. of the mineral matter shall remain suspended in water for 15 seconds.

Mr. Harrison. MR. HARRISON.—I also found, in some experiments in mixing bitumen with Portland cement, that Portland cement is not an absorbent of bitumen. It requires very much less pure bitumen mixed with Portland cement to make a homogeneous body—a hard mastic—than if mixed with most other materials of the fineness of Portland cement. The more foreign matter there is in the mastic, whether vegetable, mud, clay, or any matter which absorbs bitumen, the less the efficiency of the mastic. A mastic composed of a proportion of coarse sand, very fine sand, and Portland cement, so as to fill up the voids, requires less pure bitumen to make a good mastic than any mixture I have ever tried. There being no substance in the mixture which is an absorbent of bitumen; each molecule being coated with the bitumen forming the bond, the mastic is stronger and much more lasting, than if mud or clay are among the ingredients. I believe, as a result of long tests, that the presence of mud, clay or any substance which absorbs bitumen, whether in the bitumen itself or in the sand composing the mastic, is just as detrimental to the efficiency of the mastic, as loam, clay or any other absorbent of Portland cement is to a concrete mixture.

Mr. De Knight. MR. DE KNIGHT.—The point I have in mind is this: all earth contains lime, in either carbonate or sulphate. When we take sand and put it into bitumen, the lime in the sand or the mud injures the bitumen in time. I think that is why so many mastics and so many asphalt pavements deteriorate in time, the lime decomposing the bitumen or oils therein.

Mr. Forrest. MR. FORREST.—Just one remark in connection with Mr. Harrison's statement, that is: that Mr. Harrison's experience has been contrary to the experience of those who have been engaged in laying a great many million yards of sheet asphalt pavement.

His statement in regard to the lime might apply so far as free lime or caustic lime is concerned; but lime in the form of carbonates is a material that has been used almost since the inception of the industry as a filler in pavements; and it is regarded as an extremely desirable form of material for that use. Mr. Forrest.

MR. C. W. BOYNTON.—Is it not true that Portland cement is frequently introduced? I question the idea of lime in any form being injurious. Mr. Boynton.

MR. FORREST.—Yes, the introduction of Portland cement into sheet asphalt pavement is regarded as extremely good practice. Where the municipalities are willing to pay for that we are very glad to do it; and we consider it very good practice to do so. Mr. Forrest.

MR. VOORHEES.—I should like to ask Mr. Forrest if the Portland cement serves any other function than that of a finely ground filler. There could be no chemical action with the bitumen. How can the chemical effect of the Portland cement be obtained without moisture? Mr. Voorhees.

MR. FORREST.—Why Portland cement is a particularly desirable or superior material to use in a sheet asphalt pavement has never been fully explained. We know that it is; and Mr. Richardson has not attempted to explain why it is. As he has had a great deal more experience in the handling of asphalt mixtures than I have had, I should not care to assume the responsibility of advancing on his behalf a theory, as to why Portland cement is actually a very superior material to use as a filler, and superior to ordinary limestone. Mr. Forrest.

MR. CYRIL DE WYRRALL.—Regarding the hydrating of cement, I was surprised about six years ago in mixing cement with petroleum residuum, to find that it did hydrate to a great extent. I could not see why it should; but the material was heated and did not contain water; I wanted to make a mastic for a certain purpose and the material got hard and developed a good deal of tensile strength. The oil was heated to 112° C. Mr. De Wyrrall.

MR. VOORHEES.—I think all of us have had experiences with the absorption of moisture in oils when exposed to moist atmospheres. Mr. Voorhees.

MR. BOYNTON.—I know of a large paving concern using, during the last year, at different times, both Portland and Puzzolana cement to mix with asphalt, and I do not believe that the chemical Mr. Boynton.

Mr. Boynton. action was considered. It was a fine material that was wanted and the opinion was that Puzzolana cement gave better results than Portland cement because it was finer. Does anyone know of hydrated lime, which is still finer, being used in this way?

Mr. Forrest. MR. FORREST.—Yes, it has been used; and it has not proved a satisfactory material; nor has natural cement, which is apt to contain free lime, proved a desirable material as a substitute for Portland cement.

Mr. Harrison. MR. HARRISON.—In my experiments in mixing bitumens with both Portland cement and hydrated lime, I found that the Portland cement seemed to take its set in about the same period of time, relatively, as it would if it were hydrated by water; that is to say, as 7, 14, 21, 28 days the hardness of the material seemed to be relatively the same as when hydrated; whereas, in the mixture with hydrated lime the material remained plastic for a very much longer period, showing entirely different results than that with Portland cement.

THE DEVELOPMENT OF THE TEST FOR THE CEMENTING VALUE OF ROAD MATERIAL.

By Allerton S. Cushman.

The old idea that any stone was good enough to build a road of has been replaced by the knowledge that rocks, even of the same type, vary within wide limits in their physical properties, some of them being quite unsuited for road building. It is evident that in order to keep a road surface compact and in good order, not only must dust be continually worn off to take the place of that removed by various agencies, but also the dust which has formed must be capable of forming a bond between the larger stones which make up the aggregate.

The first attempt to develop a test for cementing value was made by L. W. Page in 1893, working in cooperation with the Massachusetts Highway Commission. In the earlier attempts the fine dust which was worn off in the abrasion test and which had passed a 100-mesh sieve was tempered with water and test pieces were molded from it of varying sizes and shapes. It was found that neither compression nor tension tests gave satisfactory results, and the method finally adopted consisted in molding test pieces in a cylindrical die under a definite pressure. The test pieces which were finally adopted were 25 mm. in diameter and 25 mm. high. These little cylindrical briquettes, after being thoroughly and carefully dried, were broken under the impact of a 1-kg. hammer falling 1 cm., the blow being repeated until failure occurred. The details of the method and the machine used have been published in several places and need not be repeated here. In later work the practice of using the dust from the abrasion test was discontinued and a definite quantity of the stone was ground to a fine powder in a heavy iron ball mill. The fine dust resulting from this grinding was passed through a 100-mesh sieve and the test pieces molded as described, a hydraulic press being used to apply a definite load at a definite rate.

In the earlier practice it was the custom to make a recementation test. The fragments of the briquettes from the cementation test were ground, again mixed with a definite quantity of water

and immediately remolded into briquettes. This was done on the theory that the rock dust on a road surface is continually being cemented, broken up, and recemented under traffic. A very large number of tests showed that the recementing values in by far the larger number of cases were smaller than the corresponding cementing values. There were, however, a number of cases in which the reverse took place. This is shown in the following table, in which the cementing and recementing values of a number of rock species are compared:

TABLE I.—COMPARISON OF CEMENTING AND RECEMENTING VALUES.

Serial No.	Name.	Cementing value.	Recementing value.
335	Diabase (trap)	110	89
336	Ferruginous limestone	158	72
337	Dolomitic limestone	59	42
338	Novaculite (chert)	24	18
340	Limestone	95	29
343	Dolomite	32	23
344	Sandstone	54	23
349	Diabase (trap)	49	44
346	Limestone	8	13
351	Gravel	11	13
383	Limestone	22	34
403	Limestone	110	126
492	Dolomitic limestone	22	30
497	Hornblende schist	7	9

These anomalous results called for a thorough investigation of the whole question. As it is well known in clay working that the soaking and kneading of a clay for protracted periods increases not only its plasticity, but also its binding power, it was suspected that the prolonged action of water on fine rock dust might well increase the binding power at least up to some maximum value. Investigations were at once begun to see if the underlying cause of the cementing power could be discovered. It is sufficient to say here that the conclusion was reached that the rock powders which have binding power invariably undergo decomposition under the action of water, the decomposition products forming soft, more or less adherent films on the surface of the particles. On drying out, this adherent bond locks the particles together. In the case of clays this bond is usually very

strong, while with rock dust it is extremely variable, ranging from those rock powders which yield briquettes that break on the first blow, to those which will sustain hundreds of blows without failure.

After the observations had been made which led to the conclusions outlined above, it became evident that a modification was necessary in the manner of making the briquettes for the cementation test. Since the bond is developed under the prolonged action of water, it is manifestly unfair to wet the rock dust and immediately mold the test pieces. Moreover, as the

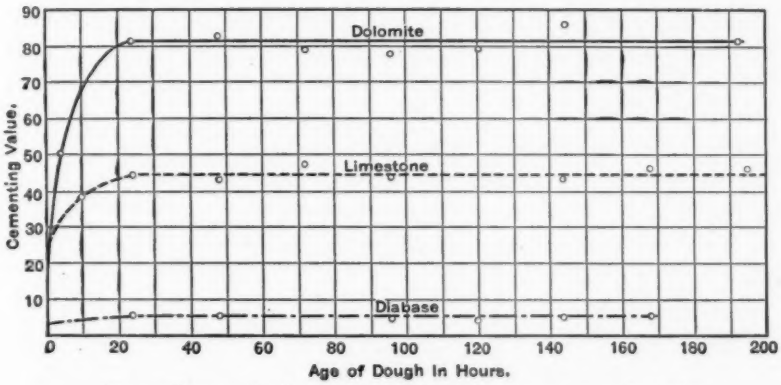


Fig 1.--Diagram showing prolonged effect of water on cementing value.

action of water begins at once, and according to the laws of physical chemistry, is more rapid at first, slowing down gradually as the point of completion of the reaction is approached, it is apparent that considerable error in the results may be occasioned by small variations in time after the wetting of the dust takes place until the briquette is molded. It will also be shown that with nearly all materials the amount of working or kneading which is done upon the wet mass will effect the softening of the particles, and hence strengthen the bond. These variations were sufficiently large in some cases to account for the anomalous results in the cementation and recementation tests; hence the recementation tests were immediately given up as being of no value, and methods were devised by which the cementation test should be improved.

The finely ground and sifted rock dusts were mixed with

a sufficient quantity of water, and were worked and kneaded until a stiff dough of even consistency was obtained. From these doughs series of briquettes were made at intervals and tested. The effects produced by age on doughs of three typical specimens, including samples of good, medium, and poor cementing values, are given in the curves shown in Fig. 1.

A study of these curves shows that there is invariably a rapid rise in binding power in the newly-made doughs, and that after the lapse of twenty-four hours the value has, for the purpose of the test, become practically constant. This effect, is of course, more apparent in materials of high cementing value than in materials of lower values. Numerous experiments have shown that with powders, as with fine sand, having no particles of a colloidal nature, and therefore no binding power, soaking or kneading will not develop the slightest increase. In carrying out the cementation test, the doughs were invariably aged for at least twenty-four hours, and the workman was trained to knead the dough always in the same manner for about the same length of time. Careful attention to these details resulted in a great improvement in the value of the test, both in a lessened percentage of variation in different test pieces of the same series, and also in the agreement of the tests with the results of service.

Rocks are far from being homogeneous materials, and in addition the cementing power itself is such a variable quantity that it may be said that the test has served its purpose if it does no more than distinguish high binding material from that which is only fair, and this in turn from that which has little or no binding power.

Further experiments which were undertaken later showed that the binding power is still more increased if the dough or paste of rock dust is kneaded or worked by hand. This is plainly shown by the results obtained on a sample of dolomite which is celebrated as a binding material in the locality in which it occurs. The most marked characteristic of this rock is the way that its binding power increases after it has been on the road for some time. The results shown in Table II were obtained by mixing the sifted dust with water and molding briquettes of the paste at separate intervals; finally a new lot of the dust was made into a paste and well kneaded by hand for one hour.

TABLE II.

Time.	Cementing Value.
At once	16
Dough 4 hours old	50
" 24 " "	81
" 72 " "	79
" 96 " "	77
" 120 " "	79
" 144 " "	83
" 8 days "	81
" kneaded 1 hour	190

It now became apparent that a system of wet grinding would develop much higher values than could be obtained by grinding the sample dry and subsequently mixing with a given amount of water. In order to investigate this point, a series of experiments was made in which kilogram charges of rock dust were ground with approximately 20 per cent. by weight of water in the ball mill for three hours. Without exception the binding power has been increased by this method of procedure, as is shown in Table III.

It has been shown in previous publications that the binding power of rock dust depends upon the decomposition of the mineral constituent of the rock under the action of water. The decomposition products which are formed principally as films on the surface of the particles, may not invariably cause a strong bond of cementation, as they are not all alike in this respect, but wherever a bond is formed it is certain that more or less decomposition has taken place. In view of this fact, it is quite apparent that the effect produced by kneading and wet-grinding is due to the increased action of the water. Under the action of iron-shod traffic a road surface is frequently being acted on by a species of wet-grinding, and it is precisely for the reason that automobile traffic has no such action that a new problem has arisen in highway maintenance of late years. The action of water under the roller in aiding the formation of the original bond is well known to engineers, and in macadam construction the roadway is generally liberally sprinkled while the final consolidation is going on. It would appear from what has been said that in the case of most rocks, the more wet rolling they receive the better the result.

TABLE III.—RELATIVE CEMENTING VALUE OF VARIOUS ROCK SAMPLES WHEN GROUND WET AND DRY.

Serial No.	Kind of Rock.	Cementing Value.		
		Dry Grinding.	Wet Grinding.	Increase.
393	Chert	6	23	17
756	Dolomite	28	31	3
841	Diabase	15	121	106
865	Granite	13	15	2
936	Sandstone	25	78	53
977	Limestone	9	28	19
980	Basalt	128	500	372
986	Basalt	12	125	103
987	Basalt	15	25	10
988	Basalt	21	421	400
999	Eclogite	15	130	115
1003	Sandstone	61	174	113
1005	Feldspathic sandstone	10	35	25
1006	Chert	7	18	11
1008	Gneissoid granite	1	35	34
1009	Dolomite	32	174	142
1010	Slate	14	43	29
1011	Gneiss	2	52	50
1012	Epidosite	12	83	71
1015	Dolomite	13	43	30
1016	Chert	1	22	21
1017	Hornblende granite	1	29	28
1018	Quartzite breccia	1	13	12
1019	Granite	1	53	52
1020	Arposic gneiss	4	33	29
1021	Granite	1	25	24
1022	Altered peridosite	14	30	16
1023	Altered diabase	8	208	200
1024	Altered diabase	10	75	65
1025	Feldspathic basalt	108	162	54
1026	Banded chert	1	12	11
1027	Chert	12	106	94
1028	Arkose	17	200	183
1032	Limestone	5	79	74
1037	Argillite (slate)	29	179	150
1038	Limestone	14	113	99
1040	Altered diabase	11	27	16
1042	Diabase	2	101	99
1044	Diabase	8	95	87
1061	Diabase	5	58	53
1072	Limestone	38	97	59
1074	Sandstone	12	34	22
1075	Slate	7	25	18
1076	Dolomite	5	48	43
1077	Dolomitic limestone	2	18	16
1079	Syenite	5	20	15
1080	Dolomitic limestone	6	55	49
1081	Limestone	17	55	38

The latest experiments made have developed a field of investigation which promises to be of great interest, both on the theoretical and the practical sides. It appears that the addition of lime or limestone will greatly increase the cementing value of an acidic rock like granite. The results shown in the following table were obtained by mixing together equal quantities of limestone and granite rock powders of known cementing value and grinding the mixture with water.

Limestone. C. V.	Granite. C. V.	Combination. C. V.
20	6	82
26	7	53
22	9	56
13	10	22
27	3	110
26	7	38

It is well known to agricultural chemists that the addition of lime and land plaster to a soil hastens the decomposition of the natural silicates, thus setting the mineral plant foods free. It would now further appear that the scientific road builder should seek to blend his materials, wherever such a thing is possible, so as to bring about the greatest amount of decomposition possible among the rock particles on which he depends to form the bonded surface of his road.

NOTES ON THE HARDNESS AND ABRASION TESTS OF ROAD MATERIALS.

By P. L. Wormeley, Jr.

The term hardness as applied to road materials has been defined as "the resistance which a material offers to the displacement of its particles by friction," and in the laboratory of the Office of Public Roads the test for hardness is made in accordance with this definition.

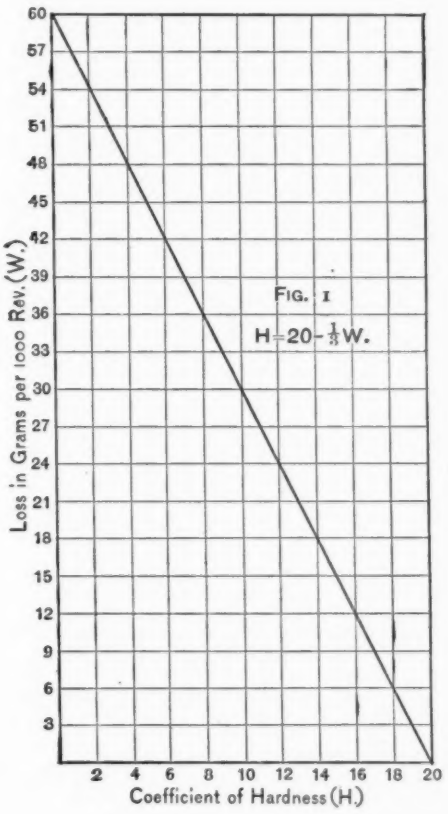
In conducting this test, cylindrical rock cores 25 mm. in diameter are held endwise against the surface of a steel disk revolving in a horizontal plane at the rate of 30 revolutions per minute. Provision is made for testing two samples at the same time by means of metal clips which hold the cores at a distance of 26 cm. from the center. The clips which are held in position by suitable metal guides are weighted so as to produce a normal pressure of 1,250 grams between the rock cores and grinding disk. Crushed quartz sand between 1 and 2 mm. in size is fed in the path of the specimen to act as the abrasive agent. When 1,000 revolutions have been completed, the loss in weight is determined, after which the operation is repeated with the specimens reversed. The average loss in weight computed from the two runs, is used in determining the hardness of the rock. In the earlier work of this office, the loss in length was determined from measurements taken before and after each run. The average loss expressed in mm. per 1,000 revolutions, subtracted from 20, was taken to represent the hardness of the specimen. The arbitrary constant 20 was selected with a view to giving the results of this test about the same range of variation as the French coefficient of wear, which will be discussed later.

It has been found, however, that although the hardest rocks lose only about 2 mm. per 1,000 revolutions, some of the softer varieties lose considerably more than 20 mm., thus giving rise to negative values in the results of the test. These negative values naturally led to more or less confusion as to their meaning, and

in order to avoid this trouble, a different formula for expressing the hardness has been adopted as follows:

$$H = 20 - \tfrac{1}{3} w \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where H = hardness and w = loss in grams per 1,000 revolutions.



According to this formula, a rock of average specific gravity (say 2.75) having zero hardness, would lose 60 grams in weight, or 45 mm. in length, corresponding to a hardness of —25 on the scale formerly used. Since no rock as soft as this would have any value for road building except as a surfacing material, all rocks losing more than 60 grams per 1,000 revolutions are reported as having zero hardness.

It would be possible to avoid negative values for hardness by adopting a formula similar to that used for computing the French coefficient of wear (eq. 2) but such a scale of hardness would be open to the same objections as will be pointed out in connection with the abrasion test. Equation 1, however, which is represented graphically in Fig. 1, has the very decided advantage of giving a uniform variation in hardness for equal losses in weight. The present method of computing hardness possesses a further advantage over the method formerly employed, in that differences in weight can be more accurately and more quickly determined than differences in length. This is especially true in the case of the harder rocks whose loss per 1,000 revolutions is very small. It may be further urged in support of the present method of conducting this test, that the slight, but unavoidable variation in the diameter of the rock cores does not appreciably affect the result. Experiments are now being made with a view to selecting if possible, a more satisfactory abrasive material. Although this work has not been carried far enough to justify any recommendation at present, it would appear from a number of tests which have been recently made, that more accurate and more uniform results may be expected if a quartzite crushed to a smaller size be used.

We will now turn to the abrasion test which to the highway engineer, is one of the most important used to determine the quality of stone for road building. This is one of the two tests which, up to the present time, have been standardized by the American Society for Testing Materials.

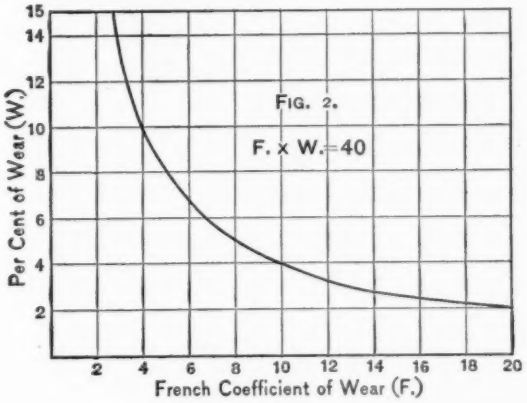
A detailed description of the test as now conducted, may be found in the Proceedings of the Society, 1904, Vol. IV, p. 193, but for the purpose of this paper, it is only necessary to give a brief description of it. An iron cylinder containing a definite weight of rock broken to the proper size, is given 10,000 revolutions at the rate of about 30 per minute, after which all material below a certain size, which has been worn off in the test, is weighed, and from this weight the per cent. of wear and the French coefficient of wear are computed. The per cent. of wear of course varies directly as the weight of rock worn off, and thus a comparison between the wearing qualities of any two rocks may be readily made on this basis; but not so with the French coefficient, for the relation

existing between the French coefficient of wear (F) and the per cent. of wear (w) when reduced to its simplest form, is

$$F \times W = 40 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

This is the equation of an equilateral hyperbola, which shows clearly (Fig. 2) that differences in the French coefficient of wear are not proportional to the corresponding differences in the per cent. of wear, that is, to the corresponding differences in the resistance to abrasion.

By reference to Fig. 2 it will be seen that in the case of rocks showing a high resistance to wear, very small differences in the



per cent. of wear correspond to large differences in the French coefficient of wear, whereas for the softer varieties of rock, the French coefficient of wear varies much less in comparison with the per cent. of wear. For instance, consider the case of two rocks which give French coefficients of wear of 16 and 20, these values being frequently obtained in testing granite, trap, etc. It might appear from these figures that there is a marked difference in the wearing qualities of the two rocks, but as a matter of fact the real difference which is found by comparing the corresponding losses in weight, turns out to be only one-half of 1 per cent., a difference which might be expected in two tests of the same sample.

On the other hand, take two samples of softer material, giving French coefficients of 2.5 and 4.0 as in the case of many limestones. This small difference of 1.5 in the French coeffi-

cient of wear, corresponds to a difference of 6.0 in the per cent. of wear, showing that the rocks are widely different in their resistance to abrasion. It is evident from the foregoing that comparisons should be made only by reference to the per cent. of wear.

The writer would limit the use of average results obtained from this test to cases where the range of variation is small, but if average results are used, as for instance in determining the probable wearing quality of any type of rock, it is a fact admitting of simple demonstration, that the average value of any number of French coefficients of wear is greater than the value corresponding to the average of the per cents. of wear, and a question naturally arises as to which of these averages represents the average resistance to abrasion. The answer is undoubtedly the average per cent. of wear, which exhibits in the simplest possible way the average wearing quality of the rocks tested. By way of illustration, the following case may be cited: In averaging the results of 50 tests of sandstone, the average per cent. of wear was 8.9. Now by substitution in eq. 2, we find that the French coefficient corresponding to a per cent of wear 8.9 is 4.5, but by averaging the French coefficients representing the 50 tests, the value 10.8 is obtained. This latter value certainly does not represent the average wearing quality of these sandstones.

Although the French coefficient of wear has been employed in road material laboratories for a number of years and is familiar to most highway engineers, it is nevertheless an irrational coefficient, and serves its purpose only partially and indirectly.

MEMOIRS OF DECEASED AMERICAN INVESTIGATORS WHO HAVE CONTRIBUTED IN A MARKED DEGREE TO THE ADVANCE OF THE TESTING OF MATERIALS.

By Gaetano Lanza.

BVT. MAJOR WILLIAM WADE.

Born in Springfield, N. J., November 17th, 1789; died in Allegheny, Pa., January 26th, 1875.

Military Record:—

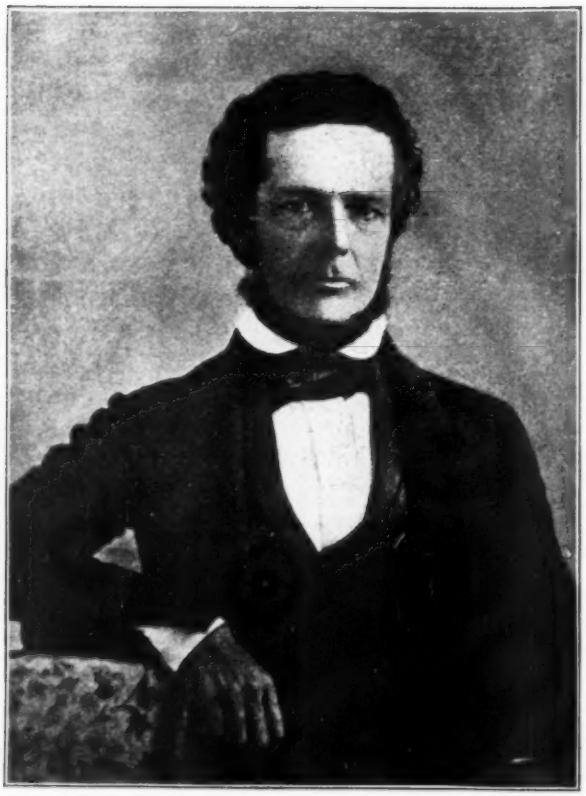
1st Lieut.	*Ordnance*	*Nov. 12th,*	1813
Captain	*Ordnance*	*Feb. 9th,*	1815
	Artillery	*June 1st,*	1821
Bvt. Major		*Feb. 9th,*	1825
Left the service		*May 20th,*	1832

From 1832 to 1837, he was a member of the firm of McClurg, Wade & Co., owners of the Fort Pitt Iron Foundry.

From 1837 to 1853, he was in the service of the United States, in the capacity of Civilian Inspector of Ordnance, and at one time, between 1837 and 1840, he was a member of the Board that visited Europe, to inspect Ordnance Manufactures.

About 1853, he left the service, and entered into partnership with Charles Knap in the Fort Pitt Foundry, in which position he remained until 1858, when he retired from the firm, and for a short time, was again in the Ordnance service. He retired from active life in 1863.

His principal publications upon the strength of materials are included in the volume—"Reports of experiments on the strength and other properties of Metals for Cannon by Officers of the Ordnance Department U. S. Army"—1856.



Bvt. Major William Wade.
1789–1875.

They included the following:—

I. Manufacture and Proof of 6 pdr. Iron Cannon ..1844
II. Experiments to Determine the Transverse Strength of Cast Iron Under Different Circumstances 1844
III. Strength of Iron, and Durability of Heavy Cannon 1844
IV. Strength of Cast Iron (continued).....1844
V. Examination of Iron Used in the Princeton Gun 1844
VI, VII, VIII. Durability of New Model 8 and 10 inch Columbiads 1844
IX, X, XI. Report of Extreme Proof of Cannon under Hydrostatic Pressure.....1844 and 54
XIII. Proof of Musket Barrels.....1846
XIV. Trial of 12-inch Columbiad Proposed by Col. Bomford 1846
XVI. Effects of Slow and Rapid Cooling.....1847
XVII. Effect of Atmospheric Pressure Upon the Surface of Liquid Iron, While Cooling 1848
XVIII. Firing Eccentric and Concentric Shells from 32 pdr. Howitzer 1848
XIX. Manufacture of 24 pdr. Iron Cannon.....1848
XX. Letter Explaining Difference of Weight in 24 pdr. Guns 1848
XXI. Density of Bronze Cannon 1848
XXII. Manufacture of One Hundred 24 pdr. Iron Howitzers 1849
XXIII. Proof of Two 8-inch Columbiads One Cast Solid, and One Hollow.....1849
XXIV. Manufacture of 32 pdr. Iron Cannon.....1850
XXV. Second Report on Proof of Guns Cast Solid and Hollow 1851
XXVII. Effect of Time in New Castings in Relieving Strains of Contraction 1852
XXVIII. Final Report on Strength and General Properties of Metals 1854

His publications included a prolonged and careful study of the methods of manufacture suitable to employ in constructing guns

that would give the best service; also of the kinds of tests to be applied to samples, so that the iron should be of such quality as to secure the best results in service. He planned, made, and studied, the results of a very large number of tests of various kinds, and these were not confined to the usual physical and chemical tests, but included also, both hydrostatic and firing tests of a large number of the guns themselves.

They involve a study of the strains due to unequal cooling, the effects of the Rodman system of interior cooling, and also, the devising of suitable methods of tests, and of suitable machinery, with which to make them.

He was one of the leaders in the development of cast iron guns, and later, as a member of the firm of the Fort Pitt Foundry, he continued to make investigations upon the strength of materials. Mr. Wm. Metcalf tells me that he, in the capacity of an engineer, in the practice of his profession, conducted all the experiments for Jones and Laughlin upon cold rolled iron, Mr. Metcalf, being, at that time, Superintendent of the Foundry, assisting him in these experiments; he found that the effect of cold rolling was to decrease the density of the iron.

Mr. Metcalf also tells me that when there was a dispute as to whether Rodman or Dahlgren deserved the credit for devising the gun associated with their names, Maj. Wade showed him a record of his own, in which he had drawn a gun of the same form, forty years before.

JOHN A. ROEBLING.

Born in Mülhausen, Prussia, June 12th, 1806; educated as a Civil Engineer at the Royal Polytechnic School in Berlin, Prussia; died in Trenton, N. J., July 22nd, 1869, from an injury received while directing the original survey for the East River Bridge.

He was first employed in superintending the construction of Public Works in Westphalia.

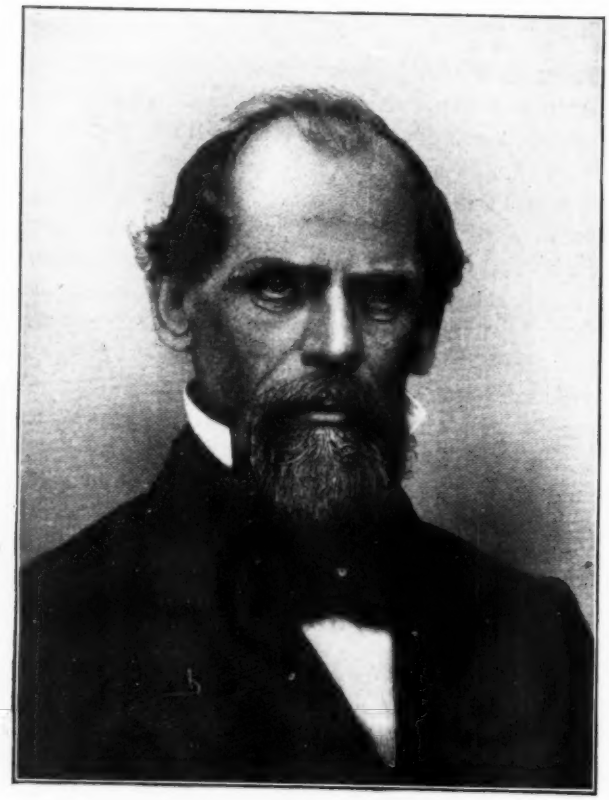
In 1831 he came to America, and settled in Saxonburg, Butler County, near Pittsburg, Pa., where he at first devoted himself to farming. Subsequently he became assistant engineer, first on the slack-water navigation of the Beaver river, second, on the Sandy and Beaver canal, an enterprise which was never completed, and third, in the construction of a feeder for the Pennsylvania Canal. He was afterwards employed in the survey of three routes for a railroad across the Alleghany Mountains from Harrisburg to Pittsburg.

We next find him making the first attempt in this country to manufacture wire rope, and devising new and improved machinery for the purpose, the first ropes having been used in the inclined planes of the Portage R. R. on the Alleghany Mountains in Pennsylvania, the machinery of which he adapted to the use of wire rope in 1840.

In 1844-45 he built the suspension aqueduct of the Pennsylvania canal across the Alleghany river which was opened to commerce in May, 1845; and, subsequently, he built four more such aqueducts, on the line of the Delaware and Hudson Canal.

In 1848 he removed from Western Pennsylvania, and established the works at Trenton, N. J., which now employ over four thousand operatives.

He was one of the leaders in the building of wire rope suspension bridges in the United States, having in 1846 advocated the building of such a bridge across the Niagara river a little below the Falls, the construction of which he commenced in 1851. This railway suspension bridge was completed, and put into service on March 18th, 1855.

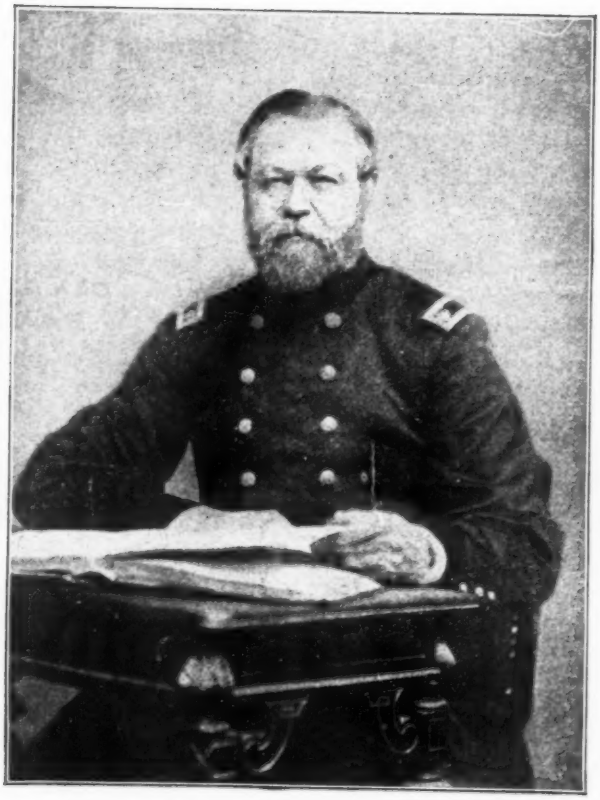


JOHN A. ROEBLING.
1806–1869.

He built many suspension bridges in different parts of the United States.

His last great work was the designing and planning of the East River Bridge connecting New York and Brooklyn, and it was while superintending the survey for its final location, that he received the injury that cost him his life.

His work as a manufacturer, together with his engineering work of designing, and erecting structures and plants involving its use, resulted in his becoming a leader in the manufacture and the use of wire rope, and through tests and experiments, in making investigations as to its strength, the quality of material to be employed, and the methods to be followed to secure the greatest strength and the greatest wearing qualities in a great variety of its applications.



Bvt. Brig. General Thomas J. Rodman
1815–1871.

BVT. BRIG. GENERAL THOMAS J. RODMAN.

Born in Salem, Indiana, July 30th, 1815; graduated at the U. S. Military Academy at West Point, July 1st, 1841; died in Rock Island, Illinois, June 7th, 1871.

Military Record:—

Bvt. 2nd Lieut	*Ordnance*	*July 1st*, 1841
1st Lieut	*Ordnance*	*March 3rd*, 1847
Captain	*Ordnance*	*July 1st*, 1855
Major	*Ordnance*	*June 1st*, 1863
Bvt. Brig. General		*March 13th*, 1865
Lieut. Colonel	*Ordnance*	*March 7th*, 1867

He was in command, at different times, of the Arsenal at Baton Rouge, La., of the Alleghany Arsenal at Pittsburg, Pa., and of those at Watertown, Mass., and Rock Island, Ill.

He was a member of many Boards in connection with Ordnance matters.

His publications upon the strength of materials are mostly included in "Records of Experiments" on the properties of metals for cannon by Capt. T. J. Rodman, 1861; and are as follows:—

I. Report of experiments made for the purpose of further testing the relative merits of Captain Rodman's mode of cooling cannon, as compared with the ordinary method. This report issued in 1857 includes (*a*) initial velocity of 10 inch shot and shells, (*b*) the velocimeter, (*c*) bursting gun heads, (*d*) indentations in copper, and pressure due to falling weight, (*e*) effects of different ratio of straining forces, (*f*) the various kinds of strain to which a gun is subjected at each discharge, (*g*) bursting effects of different weights of powder and shot in guns, (*h*) subjects requiring investigation.

II. Report on the relative endurance of guns made from the same iron, but melted in furnaces of different construction; also of guns made from the same iron melted in the same furnaces but differently cooled. This report includes (*a*) tables showing the tenacity and density of metal from the heads, and from different parts of the gun, (*b*) tables showing extension, restora-

tion, and permanent set of inner and outer specimens of different guns, (*c*) tables showing compression, etc., of inner and outer specimens from different guns.

III. Causes of difference in endurance of cannon when cast solid, and cast hollow and cooled from the exterior and the interior, 1851.

IV. Report of the fabrication and proof of two 10-inch trial guns; one cast solid, and cooled from the exterior, and the other cast hollow, and cooled from the interior. This report issued in 1858 included (*a*) tests of the iron, (*b*) tests of the guns, (*c*) mechanical tests of the metal in the guns, (*d*) enlargement of the cores by firing, (*e*) endurance of the guns.

V. Report of experiments made by Capt. T. J. Rodman in the years 1857-58 for determining the properties of gun metal, and the actual pressure per square inch due to different weights of powder and shot. This report includes (*a*) transverse resistance of guns, (*b*) deflection of bars under loads equally distributed along their whole lengths, (*c*) transverse resistance of hollow cylinders, (*d*) thickness of metal in the breech, (*e*) tangential resistance of hollow cylinders, (*f*) extensibility and compressibility of gun metal, (*g*) absolute pressure of gas in the core of a gun, (*h*) tables of pressures of gas at bottom of bars, and at two calibres from bottom in a 42 pd. gun, (*i*) time of combustion of charges, (*j*) bursting tendencies of different charges in guns of different calibre, (*k*) repetition of constant strain.

VI. Report of experiments made by Capt. T. J. Rodman, at the Watertown Arsenal in the second half of 1859 for determining the proper qualities of iron, exterior model, etc., for cannon, with special reference to the fabrication of a 15-inch gun. This report issued in 1860 included (*a*) relation between the thickness and the tangential resistance of hollow open ended cylinders by bursting them with powder, (*b*) difference of pressure due to equal columns of powder behind equal columns of metal when fired in guns of different calibre, (*c*) pressure exerted by exploded gun powder when the products of combustion occupy a certain number of times the volume occupied by the powder before combustion, (*d*) absolute pressure of powder when burned in its own volume, (*e*) effects of compressibility, (*f*) preliminary castings for 15-inch gun, (*g*) fabrication of 15-inch gun, (*h*) rate

if application of force, (*i*) difference of effect due to difference in the times of action of a given force, (*j*) experiments with powder of variable diameter of grain.

VII. Report of the Inspection, Transportation, Mounting, and Trial of the 15-inch Gun.

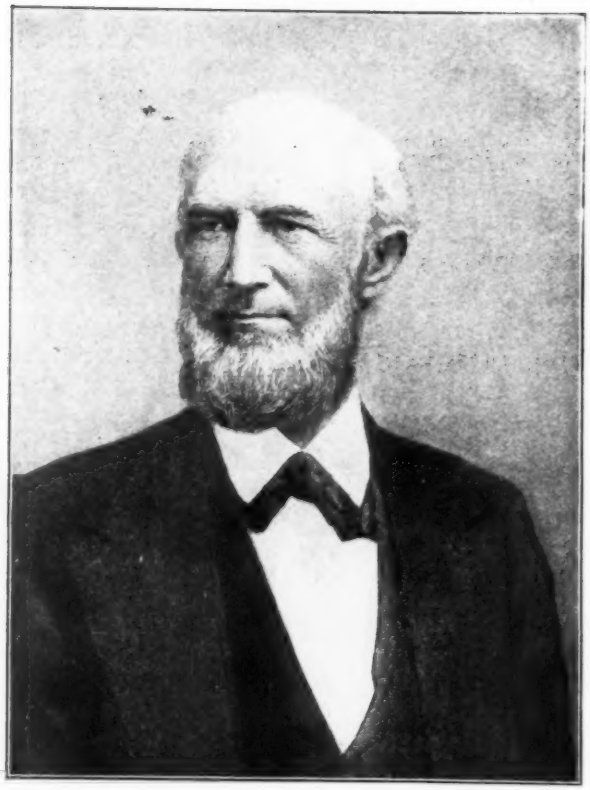
His other publications upon subjects connected with the strength of materials are as follows, viz:—

1. Bills of Iron for the Wrought Iron Brackets and Casemates Seacoast Carriages, Models of 1861, 1862, 1863 and 1864.

2. Project, Plan, Estimate, etc., for Rock Island Bridge, 1870.

He was one of the leaders in the construction of cast iron cannon, having devised the method for cooling the casting from the interior. He also made investigations on the distribution of the strains in guns, and devised the form of gun known by his name. He rebuilt the Rock Island Arsenal on a large scale, attending personally to the details.

His work included, throughout its entire course, a constant and careful investigation of strains, and of the strength and other properties of materials, especially cast iron.



JAMES B. EADS.
1820–1887.

JAMES B. EADS.

Born in Lawrenceburg, Indiana, May 23rd, 1820; died in Nassau, N. P. Bahamas, March 8th, 1887.

Prior to his work upon the St. Louis Bridge, the construction of which was begun in 1867, the principal field of his labors was connected with the Mississippi river. He began by exhibiting great courage, energy, skill and ingenuity as a wrecker on the river, raising wrecks, and clearing away obstructions in the river, and finally, during the Civil War, designing, and building iron clads, and river boats for the use of the United States Government.

From 1867 to 1874, he devoted his energies to the building of the St. Louis Bridge, and it was in connection with that enterprise that his work upon the strength of materials was performed.

Subsequently, while called into counsel in connection with many engineering works, especially those upon River and Harbor improvements in America and in Europe, his greatest work was the building of the jetties of the Mississippi river; and before his death he proposed, planned, and advocated, an interoceanic ship railway, a scheme which was never put into execution.

He was a member of the Engineers Club of St. Louis; for two years President of the Academy of Science of St. Louis; member of the American Geographical Society; of the British Institution of Civil Engineers; of the British Association for the Advancement of Science, of the Society for the Encouragement of Arts, Manufactures and Commerce; a fellow of the American Association for the Advancement of Science; and a member, and for one year Vice President, of the American Society of Civil Engineers.

In 1884, shortly after his report upon the effect that the proposed Manchester Ship Canal would have upon the estuary of the Mersey, and the bar at Liverpool, the British Society for the Encouragement of Arts, Manufactures and Commerce, awarded to him the Albert Medal. The award was made "as

a token of their appreciation of the services he had rendered to the science of engineering," to the engineer "whose works have been of such great service in improving the water communications of North America, and have thereby rendered valuable aid to the commerce of the world."

For the purposes of this memoir, however, the erection of the St. Louis Bridge is the work that demands our attention, inasmuch as the part played by Mr. Eads in the development of the subject of the strength of materials is intimately connected with its construction.

Leaving to one side the great energy that he displayed in originating, planning and carrying out this great undertaking, and the skill which he manifested in overcoming great difficulties not only in engineering, but also in the business, and in the financial line, we find that, while at that time, the manufacture and use of steel for structural purposes was in its infancy, he had the courage of his convictions, and determined to employ it.

Moreover, having made a careful study of the conditions then existing in the manufacture and use of steel, he based upon them his conclusions as to what could be done, and whenever difficulties presented themselves in obtaining the quality of metal, the tests and the constructions which he desired, he proceeded to devise ways and means for carrying out his purposes.

In so doing he exerted a very considerable influence upon the development of the manufacture of steel. He also insisted upon having suitable tests made, and in many cases tests of full size pieces, notably in the case of the anchor bolts, the results of the tests making evident weaknesses in the methods of manufacture employed at the time, which were not generally realized. In carrying out this work, the number of tests made, and the amount of metal tested were very great.

Two special testing machines were designed and built, one having a nominal capacity of 800 tons in compression, and 500 tons in tension, which was frequently used for loads of 500 tons, much of the design of which was suggested by Mr. Eads. The other of 100 tons capacity, was designed by Col. Flad.

His chief assistant in the construction of the bridge, and

hence also in the work of securing the proper material, the means of making the proper tests, and the carrying out of the tests was Col. Henry Flad; and the data at the command of the writer is not such as to enable him to separate the portion of the work upon the strength of materials that was performed by Col. Flad, from that performed by Mr. Eads himself.

COLONEL THEODORE T. S. LAIDLEY.

Born near Guyandotte, Arkell Co., Virginia, April 14th, 1822; graduated from the U. S. Military Academy at West Point, July 1st, 1842; died at Palatka, Florida, April 4th, 1886.

Military Record:—

Bvt. 2nd Lieut	*Ordnance*	*July*	*1st*, 1842
1st Lieut	*Ordnance*	*March*	*3rd*, 1847
Bvt. Captain		*April*	*18th*, 1847
Bvt. Major		*Oct.*	*12th*, 1847
Captain	*Ordnance*	*July*	*1st*, 1856
Major	*Ordnance*	*June*	*1st*, 1863
Bvt. Colonel		*March*	*13th*, 1865
Lieut. Colonel	*Ordnance*	*March*	*7th*, 1867
Colonel	*Ordnance*	*April*	*14th*, 1875
Retired		*Dec.*	*4th*, 1882

He was in command at different times of the Frankford Arsenal, of the Springfield Armory, of the New York Arsenal, and, from April 1st, 1871, to November 29th, 1882, of the Watertown Arsenal. He was, at different times, a member of many Boards upon Ordnance matters.

He was President of the Government Board to test the strength and value of all kinds of iron, steel, and other metals, from its appointment, April 15th, 1875, until June 30th, 1879, when it ceased to exist.

His publications upon subjects connected with the strength of materials are as follows, viz:—

1. Those included in the Reports of the U. S. Ordnance Department on the Tests of Metals; in the period during which he was in command of the Watertown Arsenal.
2. Heavy Guns, Report of Board on Place, Manner, and Details of Construction of Experimental. Report Chief of Ordnance, p. 174. (C) 1872

3. Report of Experiments on the Resistance of Thick Cast-Iron Cylinders to Internal Pressures, and Reply to Remarks Made Thereon by the Ordnance Board. Pl. O., pp. 19. (Misc. Pamphlets, vol. 16.) Boston.....1881
4. Shall a Cast-Iron Rifled Gun be Tested? O., p. 16 Boston.....1881
5. Tests of Metals for Cannon. Ord. Note 40, vol. 1, p. 225. (A).....1875
6. Timber and Minerals of Deep River Country of North Carolina. No. 859, Doc. 109. (C)

His chief work upon the subject of the strength of materials consisted in advocating, securing, and using the Emery testing machine of 800,000 pounds capacity at Watertown Arsenal.

The following extracts from the Official Records of Watertown Arsenal, furnished by Mr. James E. Howard, with the permission of the Chief of Ordnance U. S. Army, will make plain the efforts of Colonel Laidley in securing this machine. Extracts from letters addressed by Col. Laidley to the Chief of Ordnance; at different dates as shown:

"July 17th, 1871.

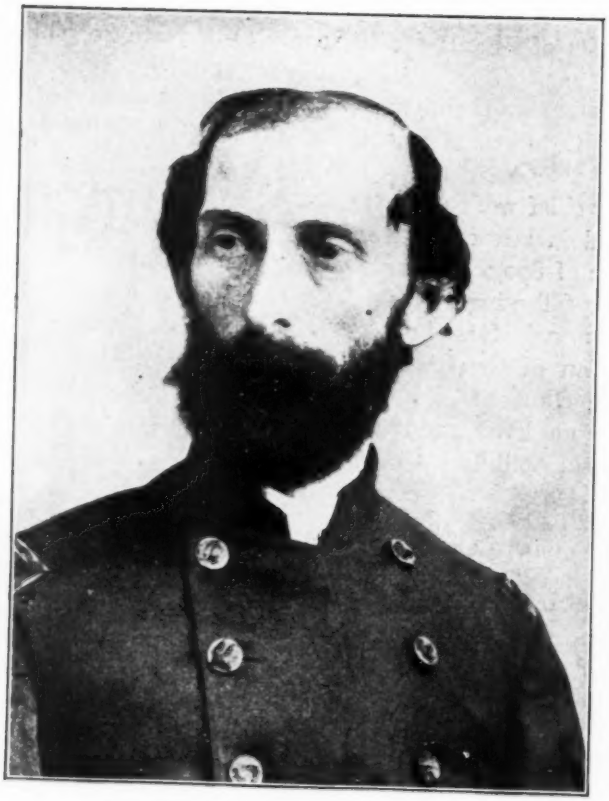
"'Colonel Laidley calls the attention of the Department 'in connection with my application of the 29th ult., to have fabricated a dynamometer (testing machine) for the use of the post,' to the difference in results of tests made on long and short specimens as made 'with Kirkaldy's large machine,' and closed by saying that this 'offers a strong argument for making a new machine which shall be more reliable and more to be trusted.'"

"October 20th, 1871.

"'Before making the estimate therein directed I have taken pains to gather all the information that I could on the subject.' Refers to recent experiments establishing the fact that small test samples 'give erroneous results;' and that 'the trial must be made if possible on the material just as it is used, or on as large samples as practicable.'"

"October 14th, 1872.

"'Desired the Ordnance Department to acquire the honor of



COLONEL THEODORE T. S. LAIDLEY.
1822–1886.

furnishing valuable, reliable data much sought for over the whole country!"

"May 29th, 1873.

"'When in Philadelphia I learned of a new testing machine which, if it will do what is claimed for it, will be just what is so much wanted. There is at Ilion, N. Y., a ten-ton scale constructed on this plan, and I think it highly desirable that I should see and examine this pair of scales. I respectfully request authority to visit Ilion, N. Y., for the purpose of making an examination of Emery's new scales?'"

"June 27th, 1873.

...."I have no hesitation in recommending to the Department the adoption of the principles of A. H. Emery's, of New York...., "I would respectfully recommend that the largest testing machine that *the funds available* for the purpose will procure be ordered from Mr. Emery for the *use of the Department.*'"

"December 24th, 1873.

'A testing machine of 400 tons capacity has been ordered from Mr. A. H. Emery by virtue of the authority contained in the 3rd Endorsement, a copy of the order is enclosed herewith,'"

"The U. S. Test Board was appointed by the President of the United States under order of March 25th, 1875, with Col. Laidley, the President of the Board. A contract was entered into with Mr. Emery, a contract being executed in place of the earlier order but for the same testing machine as before, Mr. Emery in the meantime having been engaged in perfecting the design and in making the necessary drawings."

From the above it appears that Col. Laidley in June, 1871 wrote an official letter on the subject to the Chief of Ordnance and that the further correspondence culminated in the appropriation of $25,000, and the present machine being ordered by Col. Laidley of Mr. Emery in 1873.

In 1875 the Board for testing iron, steel, etc., was appointed with Col. Laidley as President, and a contract was signed for the same machine.

The machine was not ready for use until after the expira-

tion of the Board in 1879; and during the remainder of Col. Laidley's stay at the Arsenal, he devoted himself with great earnestness to have a large number of tests made, especially upon such full size pieces as are used in Engineering practice, and to have these results published by the U. S. Government. Hence it follows that to him is due the credit for rendering possible the valuable tests made by means of that machine, in his own time, and also subsequently. The reports of these tests now number twenty-two large volumes.

COLONEL HENRY FLAD.

Born in the Grand Duchy of Baden, July 30th, 1824; graduated from the polytechnic course of the University of Munich in 1846; died in Pittsburg, Pa., June 20th, 1898.

He was employed on the Government improvements of the Rhine, and on other public works until, in 1849, he joined the revolutionary army of Southern Germany as Captain of Engineers. In the autumn of 1849, after the failure of their efforts, and under sentence of death if he should be captured, he came to America. A few years later, however, he was pardoned, so that he was free to return to Germany at any time.

He was employed successively as Draughtsman on the Erie Railroad, as Assistant Engineer on the Buffalo and Niagara Falls Railroad, and as Resident Engineer on the Ohio and Mississippi R. R.

In 1854 he went to the Iron Mountain R. R., as Resident Engineer.

On June 16th, 1861, he entered the United States Reserve Corps as a private, but was soon promoted to be Corporal, and then Sergeant. In July, 1861 he became Captain of Engineers in the "Engineer Regiment of the West" of which he became Major on Nov. 17th, 1862, Lieut. Colonel on July 30th, 1863, and Colonel on Oct. 16th, 1863.

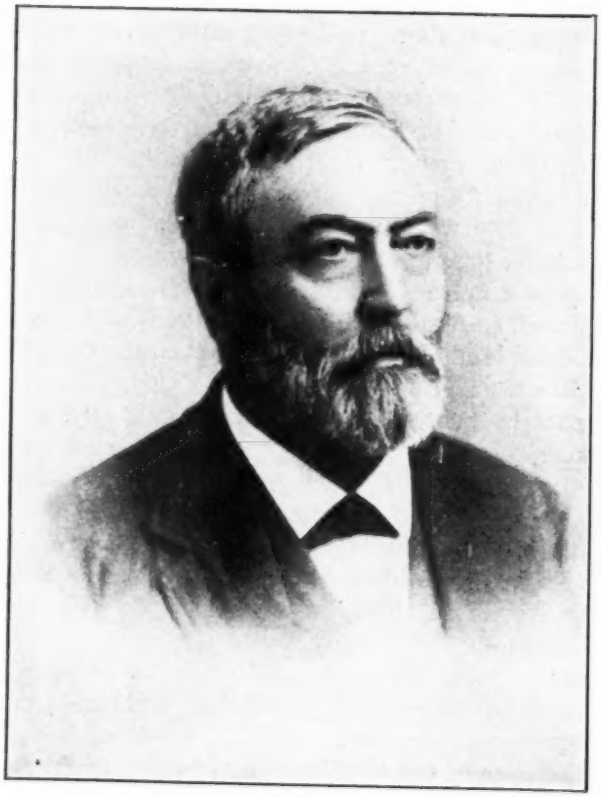
He remained in the service, performing most valuable engineering work at many places, until Nov. 12th, 1864, when the regiment was mustered out.

At the close of the Civil War he returned to St. Louis and to the practice of his profession.

In the spring of 1865 he became chief assistant to Mr. James P. Kirkwood, and was engaged in connection with him in making plans for the Waterworks of St. Louis.

In 1867 he was appointed a member of the Board of Water Commissioners for the city of St. Louis, a position which he retained until April, 1875

From 1867 to 1874 he was the right hand man of Mr. James B. Eads in the construction of the St. Louis Bridge, and it was



Colonel Henry Flad.
1824–1898.

in connection with this enterprise that his work upon the strength of materials was performed.

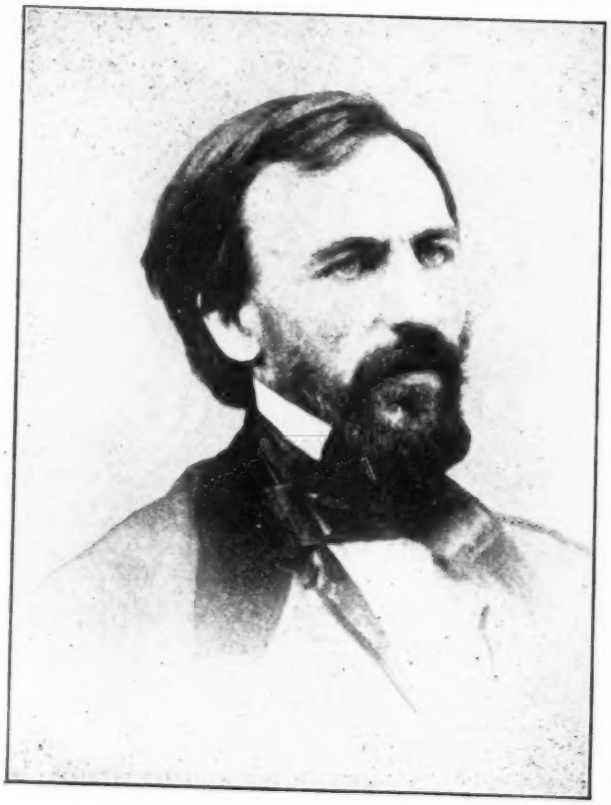
After the completion of the Bridge in 1874, he was engaged as consulting engineer in various works, and in the spring of 1877 he was elected President of the Board of Public Improvements for the city of St. Louis, a position which he held for nearly fourteen years, having been re-elected successively in 1881, 1885, and 1889. In the spring of 1890 he was appointed a member of the Mississippi Commission.

Passing now to his work upon the strength of materials, we find that it was intimately connected with the construction of the St. Louis Bridge. He was the Chief Assistant and right hand man of Mr. Eads throughout the work; and was charged with the entire responsibility during Mr. Eads's absence in Europe in the latter part of 1873.

The employment of steel in the construction of this bridge, at a time when the manufacture and use of steel for structural purposes was in its infancy, was a great step in advance, and exerted a very considerable influence upon the development of its manufacture. In carrying out the work of securing suitable material, suitable tests, and suitable constructions, the number of tests made, and the amount of metal tested was very great.

The tests upon the full size anchor bolts revealed weaknesses in the methods of manufacture employed at the time, which were not generally realized. Two special testing machines were designed and built, one having a nominal capacity of 800 tons in compression, and 500 tons in tension which was frequently used for loads of 500 tons, much of the design having been suggested by Mr. Eads. The other of 100 tons capacity was designed by Col. Flad.

In considering the work of securing the proper material, the means of making the proper tests; and the carrying out of the tests, the data at the command of the writer are not such as to enable him to separate the portion of the work that was performed by Col. Flad, from that performed by Mr. Eads.



W. E. Woodbridge.
1824–1904.

W. E. WOODBRIDGE.

Born in West Harland, Conn., November 16th, 1824; graduated at the College of Physicians and Surgeons in New York, with the degree of M. D. in 1849; died in Washington, D. C., February 26th, 1904.

From 1852 till the time of his death, he was employed under special appropriations, and orders by the Ordnance Departments of the United States Army and Navy, in various lines of research, and experimentation, and in ordnance construction.

He was a member of the United States Naval Institute.

He is best known as the first and original inventor of the expanding sabot, for giving rifle motion to cannon projectiles in 1848 to 1852.

Some of his work which attracted the early attention of the scientific world was his "Measurements of powder pressure in cannon by means of the registered Compression of Oil," which was originally published in 1890 in the Ordnance Notes, and several times republished, and in several languages.

He built the first wire wound guns in 1855.

He invented a powder pressure gauge of acknowledged excellence, an account of which was published in the Report on Ordnance Projectiles in 1880.

He also introduced a mechanical method of finding the center of gravity of cannon from drawings, which was published in "Construction der Gerogenen Geschutzrohn von Georg Kaiser Wien," 1892, and also in the Ordnance Reports.

His publications upon subjects connected with the strength of materials are as follows, viz:—

1. Experiments on the Mechanical Properties of Steel Department of Ordnance U. S. A.....1875
2. Stresses in Built-up Cannon—Ordnance Construction Notes, Ord. Dept. U. S. A.
3. Treatment of Gun Steel—Brit. Int. Civ. Engrs. vol. 89. 1887

4. Experimental Comparison of the Relative Resistances of Hollow Cylinders to Internal Pressure when Subjected to both Longitudinal and Tangential Stresses, and when Subjected to Tangential Stresses only. Report of Secretary of the Navy, U. S. A.....1886
5. Several Papers upon Wire Wound Guns.
   Ordnance Reports U. S. A.....1861 to 1894
   Brit. Inst. C. E. vol. 77. Proc. U. S. Naval Institute 1885

That Dr. Woodbridge, in connection with his work for the Ordnance Department, U. S. A., made elaborate investigations of the distribution of stresses and strains, and of the strength, and other properties of steel is evident from the short summary of his work given above, and from the list of his publications.

MAJOR GENERAL QUINCY A. GILLMORE.

Born in Black River, Lorain Co., Ohio, February 28th, 1825; graduated from the U. S. Military Academy at West Point, July 1st, 1849; died at Brooklyn, N. Y., April 7th, 1888.

Military Record:—

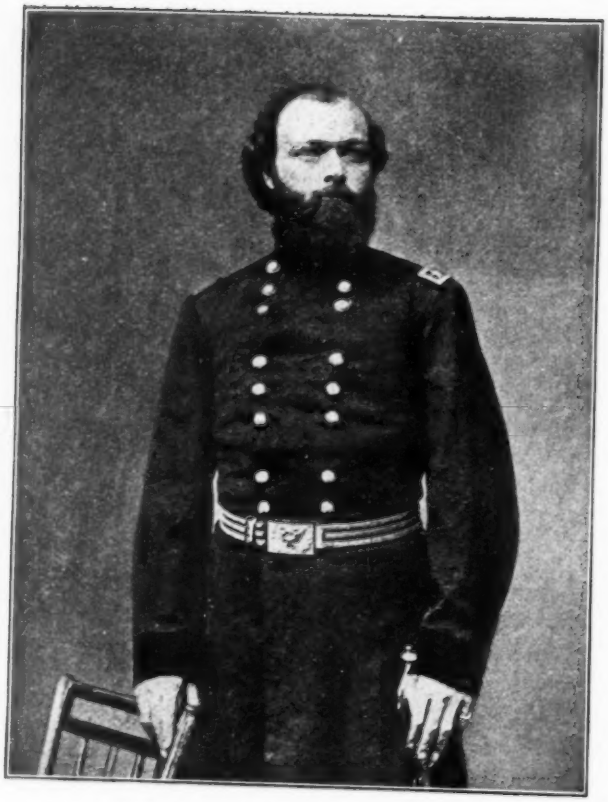
Bvt. 2nd Lieut	*Engineers*	*July*	*1st*, 1849
2nd Lieut	*Engineers*	*Sept.*	*5th*, 1853
1st Lieut	*Engineers*	*July*	*1st*, 1856
Captain	*Engineers*	*August*	*6th*, 1861
Bvt. Lieut. Col		*April*	*11th*, 1862
Brig. General U. S. Volunteers		*April*	*28th*, 1862
Bvt. Colonel		*March*	*30th*, 1863
Major	*Engineers*	*June*	*1st*, 1863
Major General U. S. Volunteers		*July*	*10th*, 1863
Bvt. Major General U. S. Army		*March*	*13th*, 1865
Resigned Volunteer Commission		*Dec.*	*5th*, 1865
Lieut. Colonel	*Engineers*	*June*	*13th*, 1874
Colonel	*Engineers*	*Feb.*	*20th*, 1883

He had a very distinguished war record, culminating in his becoming Bvt. Major General U. S. A. in 1865.

His record as a Military Engineer is also very distinguished, and very extensive, especially in connection with the improvements of rivers and harbors, and with the building of permanent fortifications; and the number of works of these characters, of which he was the Superintending Engineer, is very large, as as well as the number of Boards of which he was either President or a member.

In 1875 he was appointed a member of the U. S. Board to test iron, steel, etc.

In 1876, as one of the Judges at the Centennial Exposition, he presented to the Board of Awards, able reports on Portland, Roman, and other cements, and artificial stones, and on Brick-making Machinery, Brick Kilns, Perforated and Enameled Brick and Pavements.

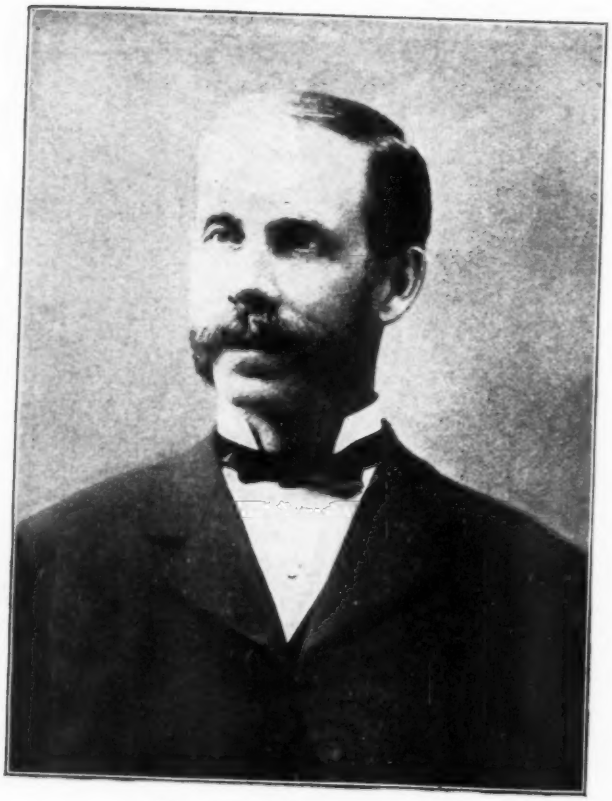


MAJOR GENERAL QUINCY A. GILLMORE.
1825–1888.

His list of publications is a long one; those bearing upon the strength of materials being the following, viz:—

1. Limes, Hydraulic Cements and Mortars. Prof'l Papers Corps of Engrs. U. S. A. No. 9 1863
2. Report on Béton Aggloméréee or Coignet-Béton and the Materials of Which it is Made. Prof'l Papers Corps of Engrs. U. S. A. No. 19, Washington, D. C.....1871
3. Coignet-Béton and other Artificial Stone, New York. Prof'l Papers Corps of Engrs. U. S. A. No. 19.....1871
4. Practical Treatise on Limes, Hydraulic Cements and Mortars. Prof'l Papers Corps of Engrs. U. S. A. No. 9. New York. 4 Editions.....1872
5. Report upon the Results of Firings to Determine the Pressure of the Blast from 15 inch Smooth-Bore Guns, Made at Staten Island, New York Harbor in 1872 and 1873. Washington, 1874. Misc. Papers.
6. Report on the Compressive Strength, Specific Gravity, and Ratio of Absorption of Various Kinds of Building Stones from Different Sections of the United States, Tested at Fort Tompkins, Staten Island, New York. Misc. Papers. Washington.....1874
7. Practical Treatise on Roads, Streets and Pavements....1876
8. Report of Experiments with the Seely and Bethell Processes for the Preservation of Timber, (and) Descriptions of these Processes and of the Hayford process. Misc. Pamphlets, Vol. 7 1879
9. Notes on Compressive Resistance of Freestone, Brick piers, Hydraulic Cements, Mortars and Concretes 1888

His extensive engineering work, together with his membership in the U. S. Board for testing iron, steel, etc., naturally resulted in activity regarding the strength of materials, especially in connection with cements, mortars, and stone, as is evidenced by his publications. He also served on the Government Board to test iron, steel, etc. (Col. Laidley, Chairman), from April 15th, 1875 to June 30th, 1879 when the Board ceased to exist.



COLONEL WM. H. PAINE.
1828–1890.

COLONEL WM. H. PAINE.

Born in Chester, N. H., May 17th, 1828; died December 31st, 1890.

In 1850 he began the practice of Engineering in Northern Wisconsin, locating roads, and surveying. In 1852 he went to California and became assistant to Col. John Plumbe, and, in this capacity, he had a wide range of experience in mining, in hydraulic and in topographical engineering, originating new methods in mining engineering.

In 1856 he became City Engineer and County Surveyor at Sheboygan, Wisconsin, and Engineer of the Sheboygan and Fond du Lac R. R.

In 1861, when the Civil War broke out, he raised several regiments for service in the United States Army, and went to Washington just before the first battle of Bull Run.

During the war he served as Captain of Engineers, the greater part of the time on the staff of the ranking major-general of the army, his special duties being in the capacity of topographical engineer. His friendship with Col. Roebling of the East River Bridge dates back to this period.

At the close of the war he resumed the profession of Engineering in Brooklyn, N. Y., and was a manufacturer of steel measuring tapes.

In 1867 he became Chief Engineer of the Flushing and Northern R. R. on Long Island, having charge of it until its completion. Throughout the erection of the East River Suspension Bridge, connecting New York and Brooklyn, he was engaged in its construction. For eighteen years, he was identified with its interest, and it was in this connection that most of his work upon the strength of materials was performed. He patented an improved cable grip, still used on the bridge.

In 1874 he became Consulting Engineer on the Hudson River tunnel, and, later, on the Port Huron tunnel under the Detroit River.

In 1877 he was engaged to examine and to report upon the safety of the cables and anchorages of the Niagara Suspension Bridge.

He was Consulting Engineer on the Tenth Avenue Cable R. R. and Constructing Engineer on the 125th street line, both in New York City. He was also Consulting and Constructing Engineer on Cable roads in Omaha, Kansas City, Denver and Cleveland.

He became a member of the American Society of Civil Engineers May 12th, 1875, of which he was Vice President from January 12th, 1882 to January 21st, 1885.

The principal work which he performed upon the strength of materials was that relating to the testing, tempering, and splicing of the cable wires for the East River Bridge, as he was in charge of the wire testing. In regard to this work Mr. Francis Collingwood says "his investigations were, *at the time*, far in advance of what had preceded." Indeed his long experience upon the East River Bridge eminently fitted him to deal with any question regarding the safety of cables.

ALEXANDER L. HOLLEY, C. E., LL. D.

Born in Salisbury, Conn., July 20th, 1832; graduated in the Scientific Course of Brown University from which he received the degree of Ph. B. in September, 1853, and that of LL. D. in 1878; died in Brooklyn, N. Y., January 29th, 1882.

After graduation he entered the locomotive department of the shops of Corliss and Nightingale at Providence, R. I., where he remained until March, 1855, when he secured employment in the locomotive works at Jersey City. While yet at the Corliss works he became a contributor to the technical press, especially to *Colburn's Railway Advocate*, of which he subsequently became the proprietor. The journal, which changed its name twice, was discontinued in September, 1857.

He then went with Mr. Colburn to Europe to study foreign railway practice and to report to a number of American railway Presidents. Their report appeared in 1858, and it exerted a very considerable influence upon the railroad practice of that time. In 1858 he became a frequent contributor to the *New York Times* upon engineering topics.

In March 1861 he was recommended for the position of United States supervising inspector of passenger steamers, by hosts of railway presidents, of engineers, and of managers of manufacturing establishments; but failing to secure the appointment, he threw his energies into the work of forwarding the interests of the Stevens battery, his efforts in this direction being partly of an engineering nature, but largely literary.

In 1863 his activity turned into a new channel, viz:—The manufacture of steel, with which he was identified for the remainder of his life.

In May 1863, he went to Europe in the interests of Messrs. Corning, Winslow & Co. to investigate the manufacture of Bessemer steel, and the works at Troy, N. Y., were built in 1865 and enlarged in 1867; in 1867 he built the works at Harrisburg, Pa. In 1868 he rebuilt the works at Troy which had been burned. Later he planned the works at North Chicago and Joliet, the Edgar Thomson works at Pittsburg and the Vulcan at St. Louis,

ALEXANDER L. HOLLEY.
1832–1882.

besides acting as consulting engineer in the designing of the Cambria, the Bethlehem, and the Scranton works.

His work increased enormously the productive capacity of that manufacture and proportionately decreased its cost. In this regard Mr. Robert W. Hunt said in 1882, just after Holley's death:

"The result of his thought gave us the present accepted type of American Bessemer plant. He did away with the English deep pit, and raised the vessels so as to get working space under them, on the ground floor; he substituted top supported hydraulic cranes for the more expensive counterweighted English ones, and put three ingot cranes around the pit instead of two, and thereby obtained greater area of power; he changed the location of the vessel as related to the pit and melting house; he modified the ladle crane, and worked all the cranes and vessels from a single point; he substituted cupolas for reverberatory furnaces; and last, but by no means least, introduced the intermediate or accumulating ladle, which is placed on scales, and this insures accuracy of operation by rendering possible the weighing of each charge of melted iron, before pouring it into the converter. These points cover the radical features of his innovations. After building such a plant, he began to meet the difficulties of details in manufacture, among the most serious of which was the short duration of the vessel-bottoms, and the time required to cool off the vessels to a point at which it was possible for workmen to enter, and make new bottoms. After many experiments, the result was the Holley vessel-bottom, which, either in its form as patented, or in a modification of it as now used in all American works has rendered possible, as much as any other one thing, the present immense production."

In 1871 he relinquished the management of the works at Troy, N. Y., and became consulting engineer to a number of works.

He, early, became interested in the Siemens Martin process and devoted much time to working out the details of the plants of which he was consulting engineer.

He also became interested in the Basic process, and it was through his efforts that the Thomas Gilchrist patents were purchased by the Bessemer Steel Company.

In June, 1875, he was appointed a member of the United States Board for testing structural materials, having been very active in securing its formation, during its life, and also in trying to secure its continuance.

In 1879 he received an appointment to lecture at the School of Mines, Columbia College, on the manufacture of iron and steel.

The Bessemer Medal was awarded to him by the Iron and Steel Institute in 1882 and forwarded to his family after his death.

The list of societies to which he belonged was as follows, viz.:—Am. Inst. Mining Engineers, of which he was President in 1875; Am. Soc. Civil Engineers, of which he was Vice-President in 1876; Am. Soc. Mechanical Engineers, of which he was Vice-President from 1880 to 1882; British Inst. Civil Engineers; and the British Iron and Steel Institute.

In October 1890 the Holley Memorial, in Washington Square, New York City, was unveiled: the inscription being as follows; viz:—"In honor of Alexander Lyman Holley, foremost among those whose genius and energy established in America, and improved, throughout the world, the manufacture of Bessemer Steel, this Memorial is erected by Engineers of two Hemispheres."

His publications upon topics connected with the strength of materials are as follows, viz:—

1. An Essay on Pen and Pocket Cutlery.....1850
2. American and European Railway Practice.....1860
3. A Treatise on Ordnance and Armor 1865
4. Steel and the Bessemer Process. Polyt. Assoc. Am. Inst.....1865
5. The Bessemer Process and Works in the United States..1868
6. Rolling versus Hammering Ingots. Am. Inst. Min. Engrs.....1872
7. Three-high Rolls. Am. Inst. Min. Engrs.....1872
8. Tests of Steel. Am. Inst. Min. Engrs.....1872
9. Bessemer Machinery. Journ. Franklin Inst. 1873
10. Recent Improvements in Bessemer Machinery. Am. Inst. Min. Engrs 1874
11. American Rolling Mills. Iron and Steel Inst. 1874

12. Setting Bessemer Converter Bottoms. Iron and Steel Inst. 1874
13. The Use of Natural Gas for Puddling and Heating. Am. Inst. Min. Engrs. 1875
14. The Form, Weight, Manufacture, and Life of Rails. Am. Soc. Civ. Engrs. 1875
15. Tests and Testing Machines. Am. Soc. Civ. Engrs. ...1875
16. Some Pressing Needs of our Iron and Steel Manufactures. Am. Inst. Min. Engrs. 1875
17. What is Steel? Am. Inst. Min. Engrs. 1875
18. Iron and Steel at Philadelphia—six papers. London Engineering .....1876—77
19. American Iron and Steel Works—forty-one papers. London Engineering .....1877 to 1880 inclusive
20. Notes on the Salisbury, Conn., Iron Mines and Works. Am. Inst. Min. Engrs. 1877
21. Notes on the Iron Ore and Anthracite Coal of Rhode Island and Massachusetts. Am. Inst. Min. Engrs. .1877
22. The Strength of Wrought Iron as Affected by its Composition and by its Reduction in Rolling. Am. Inst. Min. Engrs. 1878
23. Solid Steel Castings for Ordnance, and General Machinery by the Turneaure Process. Metallurgical Review .1878
24. Chemical and Physical Analysis of Phosphoric Steel. Brit. Inst. Civ. Engrs. .....1877—78
25. The United States Testing Machine at Watertown Arsenal. Am. Inst. Min. Engrs. 1879
26. The Pernot Furnace. Am. Inst. Min. Engrs. 1879
27. Washing Phosphoric Pig Iron for the Open Hearth and Puddling Processes. Am. Inst. Min. Engrs. 1879
28. Notes on Siemens Direct Process. Am. Inst. Min. Engrs. 1880
29. An Adaptation of the Bessemer Plant for Basic Processes. Am. Soc. Mech. Engrs. 1880
30. Steel. Appleton's Cyclopedia of Mechanics 1880
31. On Rail Patterns. Am. Inst. Min Engrs. 1881
32. The Bethlehem Iron and Steel Works. London Engineering 1881

The account of Mr. Holley's works together with the list of his publications are sufficient to make plain how very important an influence he exerted upon the manufacture of steel, our chief material of construction, and hence how large a factor his work played in advancing the subject of the strength of materials. His efforts in behalf of the work of the Watertown testing machine, and of the work of the Board being one instance of his labors along these lines.

REAR ADMIRAL LESTER ANTHONY BEARDSLEE.

Born in Little Falls, N. Y., February 1st, 1836; graduated at the United States Naval Academy at Annapolis, Md., 1856. Died in Augusta, Ga., November 10th, 1903.

Naval Record:—

Midshipman	*March*	5*th*, 1850
Past Midshipman	*June*	20*th*, 1856
Master	*Jan.*	22*nd*, 1858
Lieutenant	*July*	23*rd*, 1859
Lieutenant Commander	*July*	16*th*, 1862
Commander	*June*	12*th*, 1869
Captain	*Nov.*	26*th*, 1880
Commodore	*Jan.*	23*rd*, 1894
Rear Admiral	*May*	21*st*, 1895
Retired	*Feb.*	1*st*, 1898

He served on the United States Board to test iron, steel and other metals, from April 15th, 1875, to June 30th, 1879, when the Board ceased to exist.

He was chairman of the Committees upon chain cables, malleable iron, and reheating and re-rolling wrought iron. The results of this important research are to be found in the Report of the Board for 1881, and also in the following publication by himself; viz:—

"Beardslee on Wrought Iron and Chain Cables." Experiments on the Strength of Wrought Iron and Chain Cables. Report of the Committees of the United States Board to Test Iron, Steel and other Metals, on Chain Cables, Malleable Iron, and Reheating and Re-rolling Wrought Iron, etc. Revised and abridged by William Kent—1879.

REAR ADMIRAL LESTER A. BEARDSLEE.
1836–1903.

ROBERT H. THURSTON.

Born in Providence, R. I., October 25th, 1839; graduated at Brown University with the degrees of Ph. B. and C. E. in 1859, receiving that of A. M. in 1869, and that of LL. D. in 1889. Died in Ithaca, N. Y., October 25th, 1903.

He first worked for Thurston, Gardner and Company engine builders in Providence, R. I. In 1861 he joined the engineer corps of the U. S. Navy, and served throughout the Civil War, becoming first assistant engineer in 1864.

At the close of 1865 he was detailed to do duty in the Department of Natural and Experimental Philosophy at the United States Naval Academy at Annapolis; and he was eventually placed, *ad interim*, in charge of the Department under Admiral David D. Porter, Superintendent of the Academy.

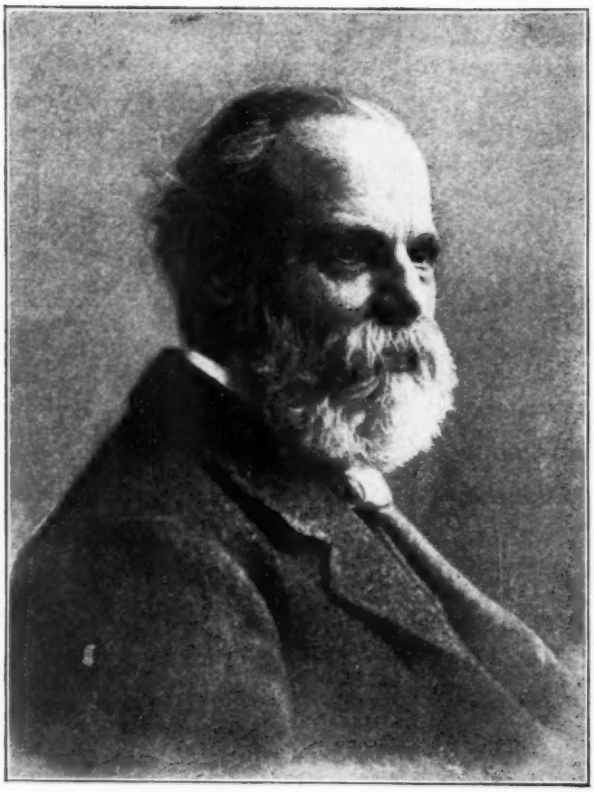
In 1870 he was appointed Professor of Mechanical Engineering in the (at that time) new Stevens Institute of Technology which position he retained until 1885, when he became the Director of the Sibley College of Mechanical Engineering of Cornell University, which latter position he retained until his death.

Besides his work of organizing and conducting these two departments successfully, he carried on from time to time, much other work.

He served as member of a United States Commission on boiler tests, and of the jury and the U. S. Commission in the Vienna exhibition in 1873. He was the editor of the Reports to the U. S. Government on that exhibition, and passed four large volumes through the press in ten months writing one of them on Manufactures himself.

He was a member, and also secretary of the United States Board to test iron, steel, etc.

He belonged to the following societies, viz:—American Association for the Advancement of Science; American Institute of New York; American Society of Civil Engineers; American Society of Mechanical Engineers, of which he was President the first two years of its existence; American



ROBERT H. THURSTON.
1839–1903.

Institute of Mining Engineers; Army and Navy Club; British Institution of Naval Architects; Royal Institution of Great Britain; British Association for the Advancement of Science; Sigma X; Engineers' Club; Franklin Institute of Pennsylvania; International Association for the Advancement of Science, Art and Education; International Association for Testing Materials; American Society for Testing Materials; Institution of Engineers and Ship-builders of Scotland; Königl-Svenska Vetenskays Academien; Naval Order of the United States; National Geographical Society; American Meteorological Society; American Historical Society; New York Academy of Science; Oesterreichische Ingenieur und Architekten Verein; Order of the Loyal Legion of the United States; Société des Ingenieurs Civils de France; Society of American Wars; Société d'Ecouragement, etc., de France; Société Industrielle de Mülhouse; U. S. Naval Institute; Verein Deutscher Ingenieurs; Washington Academy of Science.

He was a prolific writer, and has contributed much to the literature of the strength of materials. His publications upon these subjects are the following; viz:—

Published Books:

1. The Materials of Engineering. Part I. 1882. Non-Metallic Materials. Part II. 1883. Iron and Steel. Part III. 1884. Alloys and Their Constituents ..1884
2. The Materials of Construction 1884
3. Friction and Lost Work in Machinery and Millwork 1885

Articles published in the Trans. Am. Soc. C. E.:

1. Ratio of Set in Metals Subjected to Strain for Considerable Periods of Time.....1877
2. A Newly Discovered Relation Between the Tenacity of Metals and Their Resistance to Torsion 1878
3. A New Method of Detecting Overstrain in Iron and Other Materials, and its Application in Investigation of Causes of Accident to Bridges, and Other Constructions 1878
4. Variation Due to Orthozonal Strains in the Elastic Limit in Metals 1880

5. Strength and Ductility of Copper, Tin, Zinc Alloys ...1881
6. The Strongest of the Bronzes, a Newly Discovered Alloy of Maximum Strength 1881
7. Real Value of Lubricants and the Correct Methods of Comparing Prices 1885
8. Permanent Effect of Strain in Metals, Self-Registration and Mutual Interactions 1890

Articles published in the Trans. Am. Soc. Mech. Engrs.:

1. New Determinations of the Co-efficients of Friction of Lubricated Journals 1878–79
2. Theory of Rupture by Torsion and the Determination of Constants for the Formulae 1879–80
3. Newly Discovered Variation in Effect of Prolonged Stress on Iron.....1883
4. Drop Press, the Pressure Obtainable.....1884
5. Measurements of Friction 1885
6. Sliding Friction of Rotation 1885
7. Theory of the Finance of Lubrication 1885
8. Crystallization of Iron.....1886
9. Helical Seams in Boiler Making.....1887
10. Cut and Wire Nails.....1895

Articles published in the Trans. Am. Assoc. Adv. Science.

1. Tests of Iron, Steel and other Metals.....1877
2. Friction and its Laws 1878
3. Strength of American Timber 1879
4. Strength of Yellow Pine 1880

Articles published in the Franklin Institute Journal.

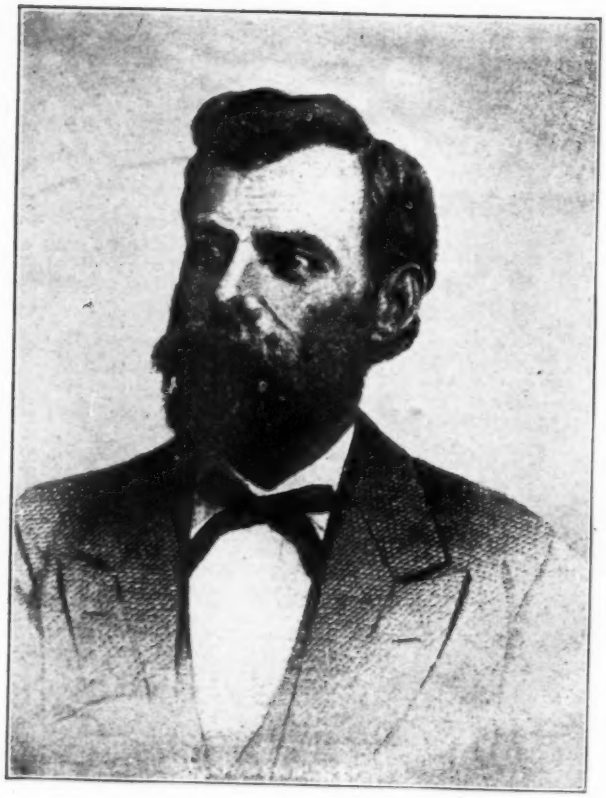
1. Torsional Resistance of Materials.....1873
2. Molecular Changes in Metals Produced by Changes of Temperature.....1873
3. Resistance of Materials.....1874
4. Strength, Elasticity, Ductility, etc., of Materials of Machine Construction.....1847
5. Mechanical Properties of Materials of Construction 1874–75
6. Coefficients, etc., of Friction of Lubricated Journals..1878
7. Strength and Economy of Materials in Steam Engines.1878

8. Experiments on the strength of Yellow Pine.....1880
9. Effect of prolonged Stress upon Strength and Elasticity of Timber 1881
10. Note on a Peculiarity Distinguishing Annealed from Unannealed Iron 1883
11. Theory of the Finance of Lubrication.....1883

In 1871 he secured for his Department at the Stevens Institute of Technology, a testing machine, and from that time on he carried on a large amount of investigation on the strength of materials, having also designed, at about that time, the torsion testing machine that is known by his name.

The work that he performed upon these subjects was partly done in connection with his commercial testing, and partly as a matter of scientific investigation. These tests covered a wide range, including iron, steel, timber and alloys. His chief investigation upon the latter subject is included in Vol. II of the Reports of the Government Board to test iron, steel, etc., of which Col. Laidley was the Chairman and Professor Thurston the Secretary. He served on this Board from April 15th, 1875, to June 30th, 1879 when it ceased to exist.

To specify in detail his subjects of investigation, along these lines is unnecessary, as the list of his publications given above, is sufficient to convey as detailed an account as there is room for in this paper.



Louis F. G. Bouscaren.
1840–1904.

LOUIS FREDERIC GUSTAVE BOUSCAREN.

Born in the island of Guadaloupe August 26th, 1840; graduated at the Ecole Centrale in Paris, France, with the degree of Ingénieur des Arts et Manufactures, in 1863; died November 7th, 1904.

After graduation he became draftsman for Samuel Hannaford and Sons, Architects of Cincinnati, in 1865 Assistant Engineer of Maintenance of Way on the Ohio and Mississippi R. R. In 1868 he was making surveys for the St. Louis and Terre Haute R. R. In 1869 he became Principal Assistant to E. C. Rice on the St. Louis and South Eastern R. R., and at the same time, Chief Engineer of the O'Fallon and Belleville R. R. In 1872 he was made Principal Assistant Engineer on the Cairo and Vincennes R. R. In 1873 he was employed under Thomas D. Lovett, to prepare specifications and to take charge of the construction of the bridge for the Cincinnati Southern R. R. over the Ohio river. In 1873 he also became Principal Assistant Engineer of Construction of the Cincinnati Southern R. R., of which he was subsequently made Chief Engineer, upon the resignation of Mr. Lovett.

In 1881 he was made Chief Engineer of the system of railroads controlled by the Erlanger syndicate, retaining this position until 1886, when he resigned.

From 1886 to 1896, he was in private practice, as consulting engineer, and, during this period, he was employed, among other engineering works, on the construction of several bridges over the Ohio river, and upon waterworks for Covington, Kentucky.

He was also a member of the committee to investigate and report upon the best plan for bridging the North River, and, in 1896 he became Chief Engineer for the Commissioners of the waterworks for the City of Cincinnati.

He was a member of the American Society of Civil Engineers, of which he was a Vice-President at the time of his death; a member of the British Institution of Civil Engineers; and of the Société des Ingénieurs Civils.

His publications connected with the strength of materials, are as follows; viz:—

1. Inspection and Maintenance of Railway Structures.
   Trans. Am. Soc. C. E. 1887
2. Strength of Wrought Iron Columns.
   Trans. Am. Soc. C. E. 1880
3. Restoration of the Cable ends of the Covington and Cincinnati Suspension Bridge.
   Trans. Am. Soc. C. E. 1893
4. Standard Specifications for Railway and Highway bridges 1886

His chief work upon the strength of materials was performed in connection with the building of the bridge over the Ohio river, for the Cincinnati Southern R. R. in 1875, and with the building of the bridge over the Tennessee river for the Cincinnati Southern R. R. Mr. Bouscaren made a large number of tests of full size bridge columns, and, notwithstanding the fact that the hydraulic press by means of which they were made, was subject to the errors arising from packing friction, they formed, nevertheless, a great step in advance, as this set of tests was one of the earliest of those made upon full size wrought iron bridge columns.

GEORGE S. MORISON.

Born in New Bedford, Mass., December 19th, 1842; graduated at Harvard University with the degree of A. B. in 1863, and from the Law School with the degree of LL. B., and admitted to the New York Bar in 1868. Died in New York City, July 1st, 1903.

In October 1867, he became assistant to Mr. O. Chanute, who was then building the first bridge across the Missouri River at Kansas City, Missouri.

In June, 1871, he became Chief Engineer of the Detroit, Eel River and Illinois R. R. In this capacity, and subsequently, in the capacity of Principal Assistant. Engineer of the Erie Railroad, he reconstructed and strengthened most of the bridges of the road, replacing the celebrated Portage bridge in 1875, by an iron structure which he designed and built.

He was, for ten years, Consulting Engineer on railway properties for Baring Brothers and Co.; and served as Director on several railroads as follows, viz.: for ten years, on the Eastern Railroad of Massachusetts; for four years, on the St. Louis Iron Mountain and Southern R. R.: for eight years, on the Maine Central R. R.; and for eight years, on the Ohio and Mississippi R. R.

Among the many bridges which he constructed, were ten over the Missouri River, five over the Mississippi River, and one over the Ohio River.

Those over the Missouri are the following, viz.: Plattsmouth, completed in 1880; Bismarck, completed in 1882; Blair, completed in 1883; Rulo, completed in 1887; Sioux City, Nebraska City, and Omaha, all completed in 1888; Leavenworth, Kansas, and Bellefontaine, Missouri; both completed in 1893; and Atchison, Missouri, completed in 1901. Those over the Mississippi are the following, viz.: Winona, Minnesota, and Burlington, Iowa, both completed in 1891; Memphis, Tennessee, completed in 1893; Alton, Illinois, completed in 1893; and Merchants bridge at St. Louis.

Over the Ohio, he built the Cairo bridge, completed in 1890

GEORGE S. MORISON.
1842–1903.

He was a member of many Government Boards, one of which, was the Isthmian Canal Commission, on which he took a decided stand for the Panama route, and another one, the Commission to report on the greatest practicable span for a bridge across the Hudson River. He was a member of the Western Society of Engineers; of the American Society of Civil Engineers, of which he was President for one year; of the American Society of Mechanical Engineers; of the American Institute of Mining Engineers; of the American Society for Testing Materials; of the British Institution of Civil Engineers; and of the Mexican Society of Engineers and Architects; an Associate Fellow of the American Academy of Arts and Sciences; and a Fellow of the American Association for the Advancement of Science.

His principal publications connected with the strength of materials are the Specifications for the various bridges built by him, especially those for the Plattsmouth, and the Memphis Bridges.

When we come to consider the part that he played in the testing of the Strength of Materials, we find that as early as 1879, he had the courage of his convictions and decided to use steel for a large portion of the Plattsmouth bridge, and that, not content with the test samples of steel, he had tests made, at Watertown Arsenal, of full size steel eye-bars, and even of one full size steel column. Moreover he continued the use of steel in his bridges, and devoted a great deal of attention to the means of securing steel suitable for bridge building. This resulted in his framing a set of specifications for the Memphis bridge, which have had a very considerable influence upon later specifications for structural steel.

JOHN B. JOHNSON.
1850–1902.

JOHN B. JOHNSON.

Born near Marlboro, Ohio, June 11th, 1850; graduated at the University of Michigan from the course in Civil Engineering in 1878. Died at Pier Cove, Michigan, June 23rd, 1902.

From 1878 to 1881 he was employed on the Survey of the Great Lakes, and from 1881 to 1883 as an Assistant Engineer of the Mississippi River Commission. In 1883 he became Professor of Civil Engineering in Washington University, St. Louis, Mo., and in 1899 Dean of the College of Engineering in the University of Wisconsin.

He was a member of the Engineers' Club of St. Louis, of which he was Secretary; of the Society for the Promotion of Engineering Education, of which he was Secretary for several years, and for one year, President; of the American Society of Civil Engineers; of the American Society of Mechanical Engineers; of the British Institution of Civil Engineers; of the International Society for Testing Materials; of the Academy of Science of St. Louis; of the Art Club of Madison; and a fellow of the American Association for the Advancement of Science.

His publications connected with the strength of materials were as follows; viz:—

1. Cast Iron, Strength, Resilience Tests, and Specifications. Am. Soc. C. E. 1890
2. Theory and Practice of Modern Framed Structures, in collaboration with Prof. F. E. Turneaure, and C. W. Bryan 1892
3. Engineering Contracts and Specifications 1895
4. The Materials of Construction 1897

His chief work upon the Strength of Materials was that which he performed in the testing of timber for the Division of Forestry United States Department of Agriculture, the account of which was published in the Bulletins of the Division, and in his book on the Materials of Construction.

ALFRED E. HUNT
1855–1899.

ALFRED E. HUNT.

Born in East Douglas, Mass., March 31st, 1855; graduated at the Massachusetts Institute of Technology in the course in Mining Engineering in 1876. Died in Philadelphia, April 26th, 1899.

At first he worked for the United States Geological Survey, but subsequently became Chemist and Assistant Manager of the Bay State Steel Company at South Boston, Mass., by which he was sent to Michigan to investigate the iron ore deposits recently discovered there.

In 1877 he became Chemist and Superintendent of the Nashua Steel Company at Nashua, N. H., and had charge of reconstructing the rolling mill, and of building a number of furnaces.

In 1881 he became Superintendent of the Open Hearth Steel Department of Park Brothers and Company, and in 1882, Assistant Manager of the Black Diamond Steel Works.

In 1883 he associated with himself George H. Clapp, and started the Metallurgical and Chemical Department of the Pittsburg Testing Laboratory having charge also of the inspecting department, and, in this capacity, he inspected the material for a great many important structures. They soon became Proprietors of the Testing Laboratory.

In 1888 he organized the Pittsburg Reduction Company, of which he was President and General Manager until the time of his death.

He served in the Volunteer Militia of Massachusetts and New Hampshire, in both of which he attained the grade of Captain. After removing to Pittsburg he organized Battery B of the National Guard, and soon became its Captain. At the beginning of the war with Spain he and his battery enlisted, and though invalided at Chickamauga he went with it to Porto Rico, and performed valuable service, especially in the engineering line.

In Porto Rico he contracted malaria, which affected his heart, and resulted later in his death.

He was a member of the Engineers' Society of Western Pennsylvania, of which he was at one time President; of the American Institute of Mining Engineers, of which he was at one time Vice-President; of the American Society of Civil Engineers, from which he received in 1893 the Norman medal for his paper on "A proposed method of testing Structural Steel": of the American Society of Mechanical Engineers; of the American Association for the Advancement of Science; of the American Chemical Society; of the British Institution of Civil Engineers; and of the Iron and Steel Institute.

His publications upon subjects connected with the strength of materials are as follows; viz:—

1. Open Hearth Steel Charge Made for Boiler Plates. Am. Inst. Min. Engrs.....1883
2. Calorimetric Determination of Carbon in Steels. Am. Inst. Min. Engrs.....1883
3. Soft Steel for Boiler Plates. Am. Inst. Min. Engrs...1885
4. Estimation of Manganese in Iron and Steel by the Color Method. Am. Inst. Min. Engrs.....1886
5. Some Recent Improvements in Open Hearth Steel Practice. Am. Inst. Min. Engrs.....1887
6. Modification of the Refining Process by the Carbon Iron Company. Am. Inst. Min. Engrs.....1888
7. Aluminum with Some Information Relating to the Metal, with J. W. Langley, and C. M. Hall. Am. Inst. Min. Engrs. 1889
8. Inspection of Materials in Construction in the United States, with G. H. Clapp. Am. Inst. Min. Engrs...1890
9. Tests and Requirements of Structural Wrought Iron and Steel. Am. Inst. Min. Engrs.....1891
10. A Proposed Method of Testing Structural Steel. Am. Soc. C. E.....1893

The work of organizing and conducting the Pittsburg Testing Laboratory as well as his previous work as Chemist and Metallurgist in iron and steel works, made him a constant student of the properties of structural iron and steel; and he not only performed a large amount of investigation along these lines, but was also in close contact with the construction of many

important works involving their use. His published papers upon these subjects furnish a portion of the results of his labors in these directions. Moreover, his organization and conduct of the Pittsburg Reduction Company, of which he was President and General Manager, led him into a careful study, and investigation of the properties, including the strength, of another metal, viz:—Aluminum, and he reduced the price of its production from fifteen dollars per pound, to about 30 or 40 cents per pound, and, as a result, it came into extensive use for many purposes, for which it was previously unavailable.

APPENDIX.

SOURCES OF INFORMATION.

MAJ. W. WADE.

1. Reports of experiments on the strength, and other properties, of metals for cannon, by Officers of the Ordnance Department, U. S. Army. 1856.
2. Information furnished by Mr. Wm. Metcalf.
3. Military record furnished by Mr. Lithgow Willey.
4. Information furnished by his son, Mr. Wm. Wade.

JOHN A. ROEBLING.

1 Stuart's Lives of Engineers.
2. Information furnished by his son, Mr. Washington Roebling.
3. Information furnished by Mr. Francis Collingwood.

GENERAL T. J. RODMAN.

1. Records of experiments on the properties of Metals for Cannon, by Captain T. J. Rodman.
2. Information furnished by Mr. Wm. Metcalf.
3. Cullom's Register of West Point Graduates.
4. List of publications furnished by Prof. E. S. Holden, Librarian of the U. S. Military Academy at West Point.

JAMES B. EADS.

1. History of the St. Louis Bridge, by Prof. C. M. Woodward.
2. Life of James B. Eads, by Mr. Louis How.
3. Obituary of James B. Eads. Trans. Am. Soc. C. E.
4. Information furnished by Mr. Theodore Cooper.
5. Information furnished by Prof. C. M. Woodward.

COLONEL T. T. S. LAIDLEY.

1. Information furnished by Mr. James E. Howard, including extracts from the Official Records of Watertown Arsenal.
2. Cullom's Register of West Point Graduates.
3. List of publications furnished by Prof. E. S. Holden, Librarian of the U. S. Military Academy at West Point.

COLONEL HENRY FLAD.

1. History of the St. Louis Bridge, by Prof. C. M. Woodward.
2. Obituary of Col. Flad. Trans. Am. Soc. C. E.
3. Obituary of Col. Flad. Mil. Order of the Loyal Legion.
4. Information furnished by Mr. Theodore Cooper.
5. Information furnished by his son, Mr. Edward Flad.

W. E. WOODBRIDGE.

All the information was furnished by Prof. S. H. Woodbridge, his nephew.

GENERAL Q. A. GILLMORE.

1. Information furnished from the Office of the Chief of Engineers, U. S. Army, by Capt. Charles M. Kutz.
2. General Orders No. 5 Headquarters Corps of Engineers U. S. Army, April 10th, 1888.
3. List of publications furnished by Prof. E. S. Holden, Librarian of the U. S. Military Academy at West Point.
4. Information furnished by his son, Captain Q. O. M. Gillmore.

COLONEL WM. H. PAINE.

1. Obituary of Col. Paine. Trans. Am. Soc. C. E.
2. Information furnished by Mr. Francis Collingwood.
3. Information furnished by his son, Mr. Washington Roebling.
4. Information furnished by Mr. C. W. Hunt, Sec. Am. Soc. C. E.

ALEXANDER L. HOLLEY.

1. Memorial of Alexander Lyman Holley, published by the Am. Institute of Mining Engineers. 1884.
2. Information furnished by Mr. R. W. Raymond, Sec. Am. Inst. of Mining Engineers.
3. Information furnished by Prof. F. R. Hutton, Sec. Am. Soc. of Mech. Engineers.

ADMIRAL A. L. BEARDSLEE.

1. Who's Who in America.
2. Information furnished by Mr. Lithgow Willey.

ROBERT H. THURSTON.

1. The Sibley Journal of Mechanical Engineering. November 1903.
2. Information furnished by Prof. Rolla C. Carpenter, of Cornell University.
3. Memorial in the Trans. Am. Soc. of Mechanical Engineers.

LOUIS F. G. BOUSCAREN.

1. Obituary in Engineering News, by Mr. Ward Baldwin.
2. Information furnished by Mr. L. H. G. Bouscaren, his son.

GEORGE S. MORISON.

1. Obituary in the Journal of the Western Society of Engineers.
2. Obituary in the Transactions of the British Institution of Civil Engineers.
3. Information furnished by Rev. R. S. Morison, his brother.

JOHN B. JOHNSON.

1. Obituary in the Journal of the Western Society of Engineers.
2. Obituary in the Transactions of the American Soc. of Civil Engineers.
3. Information furnished by Prof. F. E. Turneaure.
4. Information furnished by his brother, Mr. A. L. Johnson

ALFRED E. HUNT.

1. Obituary in the Transactions Am. Soc. C. E.
2. Obituary in the Transactions Am. Inst. Mining Engineers.
3. Obituary in the Transactions Am. Soc. Mech. Engineers.
4. Obituary in the Technology Review, by Mr. John R. Freeman.
5. Information furnished by Mr. John R. Freeman.
6. Information furnished by Mr. George H. Clapp.
7. Register of Graduates of the Mass. Institute of Technology.

CHARTER

OF THE

AMERICAN SOCIETY FOR TESTING MATERIALS.

To the Honorable the Judges of the Court of Common Pleas No. 2 in and for the City and County of Philadelphia: of March Term, 1902, No. 2056:

In compliance with the requirements of an Act of the General Assembly of the Commonwealth of Pennsylvania, entitled "An Act to Provide for the Incorporation and Regulation of Certain Corporations," approved the 29th day of April, A.D. one thousand eight hundred and seventy-four, and the supplements thereto, the undersigned, Henry M. Howe, Charles B. Dudley, Edgar Marburg, Robert W. Lesley, Mansfield Merriman, Albert Ladd Colby and William R. Webster, six of whom are citizens of Pennsylvania, having associated themselves together for the purposes hereinafter set forth, and desiring that they may be incorporated according to law, do hereby certify:

1. The name of the proposed corporation is the "AMERICAN SOCIETY FOR TESTING MATERIALS."

2. The corporation is formed for the Promotion of Knowledge of the Materials of Engineering, and the Standardization of Specifications and the Methods of Testing.

3. The business of the said corporation is to be transacted in Philadelphia.

4. The said corporation is to exist perpetually.

5. The names and residences of the incorporators are as follows:

HENRY M. HOWE, 27 West Seventy-third Street, New York.
CHARLES B. DUDLEY, Altoona, Pa.
EDGAR MARBURG, 517 South Forty-first Street, Philadelphia.
ROBERT W. LESLEY, 22 South Fifteenth Street, Philadelphia.
MANSFIELD MERRIMAN, South Bethlehem, Pa.
ALBERT LADD COLBY, South Bethlehem, Pa.
WILLIAM R. WEBSTER, "The Bartram," Thirty-third and Chestnut Streets, Philadelphia.

6. The management of the said corporation shall be vested in an Executive Committee, consisting of six (6) members, viz.: the Chairman, the Vice-Chairman, the Secretary, the Treasurer and two other members of the corporation, and such other officers as the corporation may from time to time appoint.

7. The corporation has no capital stock, and the members thereof shall be composed of the subscribers and their associates and of such persons as may from time to time be admitted by vote in such manner and upon such requirements as may be prescribed by the By-Laws. The corporation shall nevertheless have power to exclude, expel or suspend members for just or legal cause, and in such legal manner as may be ordained and directed by the By-Laws.

8. The By-Laws of this corporation shall be admitted and taken to be its laws subordinate to the statute aforesaid; this Charter; Constitution and Laws of the Commonwealth of Pennsylvania, and the Constitution of the United States; they shall be altered and amended as provided for by the By-Laws themselves; and shall prescribe the powers and functions of the Executive Committee herein mentioned and those to be hereafter elected, the times and places of meetings of the Committee and this corporation; the number of members who shall constitute a quorum at the meetings of the corporation, and of the Committee; the qualifications and manner of electing members; the manner of electing officers; and the powers and duties of such officers; and all other concerns and internal arrangements of the said corporation.

Witness our hands and seals this twenty-first day of March, A.D. 1902.

(Signed) EDGAR MARBURG,
R. W. LESLEY,
WM. R. WEBSTER,
MANSFIELD MERRIMAN,
ALBERT LADD COLBY.

BY-LAWS.

ARTICLE I.

MEMBERS.

SECTION 1. Any person, corporation or technical society can become a member of this Society upon being proposed by two members and being approved by the Executive Committee.

SEC. 2. Any member who subscribes annually the sum of fifty dollars ($50) towards the general funds of the Society shall be designated a contributing member, his rights and privileges as a member remaining unchanged. Contributing members shall be exempt from the regular membership dues.

SEC. 3. Applications for membership and resignation from membership must be transmitted in writing to the Secretary.

ARTICLE II.

OFFICERS AND THEIR ELECTION.

SECTION 1. The officers shall be a President, Vice-President, Secretary and Treasurer.

SEC. 2. The offices of Secretary and Treasurer shall be held by the same person.

SEC. 3. These officers shall be elected by letter-ballot, at the Annual Meeting, and shall hold office for two years.

SEC. 4. The Executive Committee shall consist of these officers and also the last past-President and three members, two being elected by letter-ballot at each Annual Meeting in the odd years and one at each Annual Meeting in the even years.

SEC. 5. The President shall be, *ex officio*, the nominee for American Member of the Council of the International Association.

SEC. 6. The Secretary shall receive a salary to be fixed by the Executive Committee.

SEC. 7. The officers and members of the Executive Committee of this Society to hold office until the next election under these By-Laws, shall be as follows: To hold office for two years—President, Charles B. Dudley; Vice-President, R. W. Lesley; Secretary-Treasurer, Edgar Marburg; members of the Executive Committee, Henry M. Howe and James Christie. To hold office

for one year—members of the Executive Committee, Albert Ladd Colby and John McLeod.

SEC. 8. The above officers and members of the Executive Committee, as well as all succeeding officers and members of the Executive Committee elected under these By-Laws, shall serve for the respective terms to which they shall have been elected, or until their successors shall have been duly elected.

SEC. 9. The Executive Committee shall have the power to fill any vacancies occurring in their number by death, resignation or otherwise.

SEC. 10. The election of officers and members of the Executive Committee shall be by letter-ballot. The Executive Committee, before each Annual Meeting, shall appoint a Nominating Committee, whose duty it shall be to nominate a full list of officers. The list of nominations so made shall be submitted to the membership not more than eight (8) nor less than four (4) weeks before the coming Annual Meeting.

Further nominations, signed by at least ten (10) members, may be submitted to the Secretary in writing at least four (4) weeks before the Annual Meeting, and such nominations shall also be submitted to the membership on the official ballot.

ARTICLE III.

MEETINGS.

SECTION 1. The Society shall meet annually. The time and place of each meeting shall be fixed by the Executive Committee.

SEC. 2. Special meetings may be called whenever the Executive Committee shall deem it necessary, or upon the request in writing to the President of twenty-five (25) members.

ARTICLE IV.

DUES.

SECTION 1. The fiscal year shall commence on the first of January, and all dues shall be payable in advance.

SEC. 2. The annual dues of each member shall be $5.00. Members holding membership also in the International Association for Testing Materials shall pay annually the additional sum of $1.50, which shall be transmitted by the Secretary to the International Association.

SEC. 3. Any member of the Society whose dues shall remain unpaid for the period of one year shall forfeit the privileges of membership. If he neglects to pay his dues within thirty days thereafter, and after notification from the Secretary, his name may be stricken from the roll of membership by the Executive Committee.

ARTICLE V.

AMENDMENTS.

SECTION 1. Proposed amendments to these By-Laws, signed by at least three members, must be presented in writing to the Executive Committee at least four weeks before the next Annual Meeting. In the notices for this meeting the proposed amendments shall be printed. At the Annual Meeting the proposed amendment may be discussed and amended and may be passed to letter-ballot by a two-thirds vote of those present.

If two-thirds of the votes obtained by letter-ballot are in favor of the proposed amendment, it shall be adopted.

SEC. 2. The Executive Committee is authorized to number the Articles and Sections of the By-Laws to correspond with any changes that may be made.

RULES GOVERNING THE EXECUTIVE COMMITTEE.

1. Regular meetings shall be held on the first Saturday in January, April, July and October. Four members shall constitute a quorum.

At each meeting the Secretary shall report the names of all new members and of members who have resigned during the previous quarter, and shall present a financial statement.

At the January meeting the Secretary shall report the names of all members whose dues are unpaid.

The accounts of the Secretary shall be duly audited at the middle and close of each fiscal year, and the report of the auditors shall be presented in writing at the July and January meetings.

2. Special meetings may be held at any time at the call of the President, or upon the written request of four members of the Executive Committee. The notice for such meetings shall be mailed by the Secretary at least one week in advance of the meeting, and the business shall be stated in the notice.

3. The Secretary shall transmit to the International Association within five days after the first day of January, April, July and October $1.50 for each member whose dues were paid in the previous quarter together with the names of those members.

No other expenses shall be paid except on vouchers certified to be correct by the Chairman of the Committee on Finance, or a member thereof designated by the Chairman.

GENERAL INFORMATION.

International Association for Testing Materials.

Historical.—The International Association for Testing Materials had its origin in a conference of a small group of workers in experimental engineering held in Munich in 1882, at the instance chiefly of the late John Bauschinger. Meetings on a larger scale were subsequently held in Dresden (1884), Berlin (1886), Munich (1888), Vienna (1893), and Zurich (1895). At the Zurich Congress the International Association for Testing Materials was formally organized, the Second Congress was held at Stockholm in 1897, the Third Congress met at Buda-Pesth in 1901, and the Fourth Congress assembled at Brussels in 1906.

Membership.—According to the latest official report (January, 1906) the membership is distributed as follows:

Germany, 344; Russia, 357; United States, 253; Austria, 177; France, 165; Switzerland, 75; Hungary, 76; Belgium, 45; England, 47; Italy, 47; Sweden, 50; Denmark, 50; Holland, 39; Norway, 37; Roumania, 18; Spain, 13; Portugal, 11; Servia, 3; Australia, 4; Luxemburg, 4; Brazil, 2; Argentine Republic, 1; Chili, 1; Japan, 1. Total, 1,573, representing 23 countries.

Objects.—The objects of the Association, as set forth in its By-Laws,* are: "The development and unification of standard methods of testing; the investigation of the technically important properties of the materials of construction and other materials of technical importance, and also the perfecting of apparatus used for that purpose."

The important subject of specifications has, however, also been included within the scope of the Association's activity. Thus, International Committee No. 1 has been charged to report on the following problem: "On the basis of existing specifications, to seek methods and means for the introduction of international specifications for testing and inspecting iron and steel of all kinds."

Again, in pursuance of American initiative at the Buda-Pesth Congress (1901), Committee No. 1 has been enlarged by the addition of three American members, with a view of reporting on

* These By-Laws are given in full on pp. 687–689.

"Standard International Specifications for Cast Iron and Finished Castings," and Committee No. 22 has been instructed to report "On the Feasibility of the Establishment of Standard International Specifications for Cements."

Administration.—The affairs of the Association are administered by a Council, consisting of the President and one representative (member of Council) from each country having a membership of twenty (20) or more.

Methods.—The original plan was to conduct investigations almost exclusively through the agencies of international committees. These committees proved unwieldy, however, by reason of their large membership, with the added difficulties arising from geographical separation and differences of language. In pursuance of resolutions at the Buda-Pesth Congress (1901) the Council has discharged some of these committees, reassigning the problems in part to individual referees.* In the case of questions of direct international concern the original international committees are continued.

At the international congresses the reports of these committees as well as individual contributions by members are presented and discussed.

Publications.—On May 5, 1896, the International Council effected an arrangement with the publishers of *Baumaterialenkunde*† (Materials of Construction) by which that journal became the official organ of the Association. Since July, 1896, this journal has published the Proceedings of Congresses and other official matter in German and French. The fact that the Association did not furnish printed Proceedings to members free of charge, and that no provision had been made for translation into English, gave rise to no little dissatisfaction. At the Buda-Pesth Congress (1901) the International Council was accordingly authorized to perfect a new arrangement by which all official matter is now published in three separate editions (German, English and French) and sent free of charge to every member of the Association in whatever language is preferred.

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*For complete list of problems, committees and referees, see pp. 690–697.

†*Baumaterialenkunde:* Published bi-weekly at Stuttgart, Germany, in German and French. Regular subscription price $3.50 per annum; special terms to members of the International Association for Testing Materials, $2.50 per annum. Address: Staehle & Friedel, No. 57 Tuebinger Street, Stuttgart, Germany.

ORGANIZATION OF THE AMERICAN MEMBERS OF THE INTERNATIONAL ASSOCIATION.

Historical.—With a view of bringing the members of like nationality into closer relations among themselves, and in order to simplify the management and render the work of the International Association more effective, it was decided at the Stockholm Congress (1897) to encourage the consolidation of the membership in the various countries into separate national organizations. In pursuance of this action the American members met in Philadelphia on June 16, 1898, and organized under the name of the "American Section of the International Association for Testing Materials."

In March, 1902, the Executive Committee of the American Section applied for a Charter under the laws of the State of Pennsylvania for purposes of incorporation under the proposed new name of the "American Society for Testing Materials." This Charter was duly granted, and at the Fifth Annual Meeting, held at Atlantic City, N. J., it was unanimously adopted on June 12, 1902.

At the Eighth Annual Meeting (1905) the By-Laws were amended with a view of leaving membership in the International Association to the individual option of the members of the American Society. This amendment was adopted by letter-ballot of the Society.

Objects.—The objects of the Society are essentially identical with those of the International Association, with which it stands in direct organic relation, both through its membership in the same as a body, and through the individual membership on the part of many of its members.

As stated in the Charter: "The corporation is formed for the promotion of knowledge of the materials of engineering, and the standardization of specifications and the methods of testing."

The standardization of specifications is considered one of the most important functions of the Society. The method of procedure is to submit proposed standard specifications prepared by the various committees for general discussion at the annual meetings of the Society. The specifications in their original or amended form are then referred, by majority vote, to letter-ballot of the Society for adoption as Standard Specifications. A list of the Standard Specifications thus far adopted by the Society is subjoined under *Publications*.

Representation on the International Council.—The American members are entitled to one representative on the International Council. By the new Statutes of the Association (1901): "the members of Council shall be proposed by the members of each country; their final appointment being confirmed by the Congress." According to the By-Laws of the American Society the President becomes, "*ex officio*, the nominee for American Member of the Council of the International Association."

Meetings.—The Society meets annually at a time and place fixed by the Executive Committee. Special meetings may also be called in accordance wth the provisions of the By-Laws.

Annual meetings have been held in past years as follows:

First Annual Meeting, Philadelphia, Pa., House of Engineers' Club of Philadelphia, August 27, 1898.

Second Annual Meeting, Pittsburg, Pa., Rooms of Engineers' Society of Western Pennsylvania, August 15, 16, 1899.

Third Annual Meeting, New York, N. Y., House of American Society of Mechanical Engineers, October 25, 26, 27, 1900.

Fourth Annual Meeting, Niagara Falls, N. Y., International Hotel, June 29, 1901.

Fifth Annual Meeting, Atlantic City, N. J., Hotel Traymore, June 12, 13, 14, 1902.

Sixth Annual Meeting, Delaware Water Gap, Pa., Hotel Kittatinny, July 1, 2, 3, 1903.

Seventh Annual Meeting, Atlantic City, N. J., Hotel Traymore, June 16, 17, 18, 1904.

Eighth Annual Meeting, Atlantic City, N. J., Hotel Chalfonte, June 29–July 1, 1905.

Ninth Annual Meeting, Atlantic City, N. J., Hotel Chalfonte, June 21, 22, 23, 1906.

Membership.—The number of American members at the time of the organization meeting in 1898 was 70. The membership reported at the successive annual meetings was as follows: (1899) 128, (1900) 160, (1901) 168, (1902) 175, (1903) 349, (1904) 485, (1905) 677, (1906) 835, and it is now (February, 1907), 900.

Methods.—The operations of the Society are conducted in part under the auspices of the International Association and in part independently.

The number of American representatives on international committees is fixed by the International Council. These American sub-committees are authorized, however, to increase their number at pleasure, subject always to the approval of the Executive Com-

mittee of the American Society. The sense of these enlarged subcommittees on all questions is determined by majority vote; but on the international committees the representation and the number of votes allowed remain as originally fixed by the International Council.

The American Society appoints other committees at its discretion entirely independently of the International Association. On committees concerned with subjects involving commercial interests, the policy is to accord equal numerical representation to engineers or scientists, and to manufacturers.

The Committees of the American Society are now as follows:

A. On Standard Specifications for Iron and Steel.

B. On Standard Specifications for Cast Iron and Finished Castings.

C. On Standard Specifications for Cement.

D. On Standard Specifications for Paving and Building Brick.

E. On Preservative Coatings for Iron and Steel.

F. On Heat Treatment of Iron and Steel.

G. On the Magnetic Properties of Iron and Steel.

H. On Standard Tests for Road Materials.

I. On Reinforced Concrete.

J. On Standard Specifications for Coke.

K. On Standard Methods of Testing.

L. On Standard Specifications and Tests for Clay and Cement Sewer Pipes.

M. On Standard Specifications for Staybolt Iron.

N. On Standard Tests for Lubricants.

O. On Uniform Speed in Commercial Testing.

P. On Fireproofing Materials.

Q. On Standard Specifications for the Grading of Structural Timber.

R. On Uniform Specifications for Boilers.

S. On Waterproofing Materials.

T. On the Tempering and Testing of Steel Springs and Standard Specifications for Spring Steel.

U. On Standard Specifications for Wire Rope.

V. On the Corrosion of Iron and Steel.

Publications.—The publications of the Society appeared originally at irregular intervals in the form of bulletins. Twenty-eight (28) bulletins, containing a total of 266 pages, were thus issued. In 1902 it was decided to publish the Proceedings thereafter in the form of annual volumes. In passing to this new plan

of publication the twenty-eight bulletins previously issued were counted collectively as Volume I. The first of the annual volumes, designated Volume II and issued in 1902, contains 388 pages; Volume III, issued in 1903, contains 490 pages; Volume IV, issued in 1904, contains 655 pages; Volume V, issued in 1905, contains 565 pages.*

A notable work of the Society is the framing and adoption of Standard Specifications for important commercial products. The list of standard specifications thus far adopted by the Society is as follows:

1. Standard Specifications for Structural Steel for Bridges.
2. Standard Specifications for Structural Steel for Ships.
3. Standard Specifications for Structural Steel for Buildings.
4. Standard Specifications for Open Hearth Boiler Plate and Rivet Steel.
5. Standard Specifications for Steel Rails.
6. Standard Specifications for Steel Splice Bars.
7. Standard Specifications for Steel Axles.
8. Standard Specifications for Steel Tires.
9. Standard Specifications for Steel Forgings.
10. Standard Specifications for Steel Castings.
11. Standard Specifications for Wrought Iron.
12. Standard Specifications for Foundry Pig Iron.
13. Standard Specifications for Cast Iron Pipe and Special Castings.
14. Standard Specifications for Locomotive Cylinders.
15. Standard Specifications for Cast Iron Car Wheels.
16. Standard Specifications for Malleable Castings.
17. Standard Specifications for Gray Iron Castings.
18. Standard Specifications for Cement.

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ELECTED.

1904. ABBOTT, L. S. Industrial Engineer, 770 West Adams Street, Chicago, Ill.

1906. ABRAMS, D. A. Assistant, Laboratory of Applied Mechanics, University of Illinois, Urbana, Ill.

1906. ACKENHEIL, J. D. Salesman, The Patterson, Sargent Company, 42 Hudson Street, New York, N. Y.

1904. ACKERMAN, IRA J. G. Siegel Company, 79 Duane Street, New York, N. Y.

1905. ADAIR, ARTHUR P. Civil Engineer, Room 327, Sonna Block, Boise, Idaho.

1904. ADAMS, HUGH W. Eastern Agent, Sloss-Sheffield Steel and Iron Company, 15 Beekman Street, New York, N. Y.

1904. AIKEN, CHARLES W. Consulting Engineer, 101 Castleton Avenue, West New Brighton, Staten Island, N. Y.

1902. AIKEN, W. A. General Inspector of Material, Rapid Transit Railroad Commission of New York, 613 Empire Building, Pittsburg, Pa.

1902. *†AJAX METAL COMPANY. G. H. Clamer, Second Vice-President and Secretary, 46 Richmond Street, Philadelphia, Pa.

1904. ALLCOTT, F. L. Engineer of Tests, Chicago, Milwaukee and St. Paul Railway, Milwaukee, Wis.

1903. ALLEN, A. W. Superintendent, Steel Department, Pencoyd Iron Works, 267 Rochelle Avenue, Wissahickon, Philadelphia, Pa.

1905. ALLEN, HENRY C. Special Deputy State Engineer, DeGraaf Building, Albany, N. Y.

1904. ALLEN, WALTER H. Civil Engineer, United States Navy, Navy Yard, Charleston, S. C.

ELECTED.

1906. ALLIEN, VICTOR S. Agent, Minwax Coatings, 110 East Twenty-third Street, New York, N. Y.

1905. AMERICAN ASPHALTUM AND RUBBER COMPANY. T. J. Hill, President, 721 Woman's Temple, Chicago, Ill.

1902. AMERICAN BRIDGE COMPANY. C. C. Schneider, Consulting Engineer, Fifteenth and Chestnut Streets, Philadelphia, Pa.

1904. *AMERICAN BUREAU OF INSPECTION AND TESTS. E. B. Wilson, Secretary and Treasurer, 930 Monadnock Block, Chicago, Ill.

1906. AMERICAN BUREAU OF SHIPPING. Joseph E. Borden, Chief Engineer, 66 Beaver Street, New York, N. Y.

1898. *AMERICAN FOUNDRYMEN'S ASSOCIATION. Richard Moldenke, Secretary, Watchung, N. J.

1905. AMERICAN IRON AND STEEL MANUFACTURING COMPANY. H. M. Sternbergh, Vice-President and General Manager, Reading, Pa.

1904. *AMERICAN MACHINIST. Fred. J. Miller, Editor, 505 Pearl Street, New York, N. Y.

1897. AMERICAN SOCIETY OF MECHANICAL ENGINEERS. F. R. Hutton, Secretary, 12 West Thirty-first Street, New York, N. Y.

1900. AMERICAN STEEL AND WIRE COMPANY. F. H. Daniels, Chief Engineer, Worcester, Mass.

1906. *ANACONDA COPPER MINING COMPANY. E. P. Mathewson, Manager, Reduction Works, Anaconda, Mont.

1905. *ANDERSON, HAROLD BENTLEY. Mechanical Engineer, The Winton Motor Carriage Company, Cleveland, O

1897. ANDERSON, R. WILSON. Pittsburg, Pa.

1906. ANDREWS, W. H. Manager, Pratt and Lambert, 79 Tonawanda Street, Buffalo, N. Y.

1904. ANGUS, W. F. Engineer, Montreal Steel Works, Limited, Montreal, Canada.

1906. ANTISELL, FRANK L. Constructing Engineer, Raritan Copper Works, Perth Amboy, N. J.

1902. ARNOLD, CHARLES E. Chemist, Experimental Department, duPont Company, Wilmington, Del.

1906. ARNOLD, C. M. Cement Inspector, Baltimore and Ohio Railroad Company, Sixteenth and Main Streets, Wheeling, W. Va.

1906. ASHBRIDGE, RICHARD I. D. Chief Engineer, New Jersey Short Line Railroad, 605 Land Title Building, Philadelphia, Pa.

ELECTED.

1906. AUSTEN, PETER T. Consulting Chemist, 89 Pine Street, New York, N. Y.

1904. AVERILL, F. L. Civil Engineer, Washington Representative of Robert W. Hunt and Company, Room 414, Colorado Building, Washington, D. C.

1905. AVIS, JAMES L., JR. Mechanical Engineer, Robert W. Hunt and Company, 3104 South Park Avenue, Chicago, Ill.

1902. *BAILEY, J. B. Treasurer and General Manager, Central Iron and Steel Company, Harrisburg, Pa.

1906. BAILEY, RALPH W. Chemist, 65 Columbia Heights, Brooklyn, N. Y.

1903. BAKENHUS, R. E. Civil Engineer, United States Navy. In charge of Engineering Work, Naval Training Station, Newport, R. I.

1903. BAKER, IRA O. Professor of Civil Engineering, University of Illinois, Champaign, Ill.

1904. BAKER AND CO., W. E. Engineers, 27 William Street, New York, N. Y.

1904. BALDWIN, STEPHEN W. A. L. Endicott, Hyslop Road, Fisher Hill, Brookline, Mass.

1904. BARBER ASPHALT PAVING COMPANY. J. L. Rake, General Agent, Land Title Building, Philadelphia, Pa.

1898. BARBOUR, FRANK A. Civil Engineer, Snow and Barbour, 1121 Tremont Building, Boston, Mass.

1904. BARNES, CHARLES B. 360 East Sixty-second Street, Chicago, Ill.

1904. *BARNSLEY, GEORGE T. Chief Road Engineer, County of Allegheny, Pittsburg, Pa.

1905. BARRETT MANUFACTURING COMPANY, W. S. Babcock, 17 Battery Place, New York, N. Y.

1904. *BASQUIN, OLIN H. Associate Professor of Physics, Northwestern University, Evanston, Ill.

1903. *BASSETT, WILLIAM H. Chemist in charge of Laboratories, Coe Brass Manufacturing Company, Torrington, Conn.

1903. BATEMAN, F. W. Civil Engineer, Clinton, Mass.

1906. BEALE, A. H. Manager, The Eastern Steel Company, Pottsville, Pa.

1904. BECK, WESLEY J. Superintendent, Electrical Department, American Rolling Mill Company, Middletown, Ohio.

1903. BECKETT, JAMES A. General Superintendent, Walter A. Wood Mower and Reaper Company, Hoosick Falls, N. Y.

ELECTED.

1904. BEEBE, T. E. Superintendent, International Cement Company, Elizabeth, Pa.

1906. BELDEN, A. W. Coke Expert, United States Geological Survey, Fuel Testing Plant, St. Louis, Mo.

1902. *BERGER, BERNT. Civil Engineer, Assistant Engineer to Theodore Cooper, 45 Broadway, New York, N. Y.

1904. *BERGQUIST, J. G. Superintendent, Cement Plant, Illinois Steel Company, Chicago, Ill.

1904. *BERLE, KORT. Chief Structural Engineer, Supervising Architect's Office, Washington, D. C.

1903. BERRALL, JAMES. Civil Engineer, Bond Building, Washington, D. C.

1905. BERRY, H. C. Instructor in Civil Engineering, University of Pennsylvania, Philadelphia, Pa.

1898. BETHLEHEM STEEL COMPANY. E. O'C. Acker, Assistant General Superintendent, South Bethlehem, Pa.

1904. BETTS, H. S. Testing Engineer, Bureau of Forestry, Washington, D. C.

1904. BIRD, ROBERT M. Superintendent, Treatment Department, Bethlehem Steel Company, 433 Brodhead Avenue, South Bethlehem, Pa.

1905. BIRKINBINE, JOHN. Consulting Engineer, Odd Fellows' Temple, Philadelphia, Pa.

1906. BISHOP COMPANY, J. W. 109 Foster Street, Worcester, Mass.

1896. BISSELL, GEORGE W. Professor of Mechanical Engineering, Iowa State College, Ames, Iowa.

1903. *BIXBY, W. H. Colonel, Corps of Engineers, United States Army, Room 504, Federal Building, Chicago, Ill.

1904. BLACK, ADOLPH. Instructor in Civil Engineering, Columbia University, New York, N. Y.

1904. BLANCH, JOSEPH C. Superintendent, Blanchite Process Paint Company, 139 Charles Street, New York, N. Y.

1905. BLAUVELT, W. H. Managing Engineer, Semet Solvay Company, Syracuse, N. Y.

1905. BLAUVELT, WARREN S. Superintendent, Coke Oven Department, The Solvay Process Company, Detroit, Mich.

1902. BLISS, COLLINS P. Professor of Mechanical Engineering and Director of Testing Laboratory, New York University, University Heights, New York, N. Y.

1906. BLOUGH, EARL. Chief Chemist, Pittsburg Reduction Company, Pittsburg, Pa.

ELECTED.

1906. BÖCKING, FERDINAND. Foundryman, Halbergerhütte, Brebach a. Saar, Germany

1903. BÖCKING, RUDOLPH. Halbergerhutte, Post Brebach, Germany.

1905. BOLE, WM. A. Manager of Works, Westinghouse Machine Company, East Pittsburg, Pa.

1903. *BOLLER AND HODGE. Consulting Engineers, 1 Nassau Street, New York, N. Y.

1902. BONZANO, A. President, Bonzano Rail-Joint Company, 331 South Eighteenth Street, Philadelphia, Pa.

1896. BOOTH, GARRETT AND BLAIR. Engineers and Chemists, 406 Locust Street, Philadelphia, Pa.

1905. *BORGNER, CYRUS. Fire Brick and Cement Manufacturer, Twenty-third Street above Race Street, Philadelphia, Pa.

1904. *BOSTWICK, W. A. (*Member of Executive Committee*) Metallurgical Engineer, Carnegie Steel Company, Pittsburg, Pa.

1905. BOUGHTON, W. H. Professor of Civil Engineering, West Virginia University, Morgantown, W. Va.

1904. *BOWMAN, AUSTIN LORD. Consulting Engineer; Bridge Engineer, Central Railroad Company of New Jersey, 29 Broadway, New York, N. Y.

1902. BOYNTON, C. W. Chief Inspector, Cement Department, Illinois Steel Company, 1063 The Rookery, Chicago, Ill.

1900. BRAINE, L. F. Vice President, The Rail-Joint Company, Newark, N. J.

1898. BRAMWELL, JOSEPH W. 4931 Rubicam Avenue, Germantown, Philadelphia, Pa.

1906. BRAZER, G. HERBERT. Civil Engineer, J. R. Worcester and Company, 79 Milk Street, Boston, Mass.

1904. BREGOWSKY, IVAN M. Metallurgist, Crane Company, 51 Judd Street, Chicago, Ill.

1906. *BRIGHT, H. DE H. Manager, Spring Department, Standard Steel Works, 811 Harrison Building, Philadelphia, Pa.

1905. BRITTEN, CLARENCE R. Chemist, 27 Harrison Street, New York, N. Y.

1899. BROADHURST, W. H. Chemist, Department of Public Works, Municipal Building, Brooklyn, N. Y.

1905. BROWN AND COMPANY, INCORPORATED, Wayne Iron and Steel Works. James Neale, Secretary, Pittsburg, Pa.

1903. *BROWN, CHARLES CARROLL. Editor, *Municipal Engineering Magazine*, 408 Commercial Club Building, Indianapolis, Ind.

ELECTED.

1906. BROWN HOISTING MACHINERY COMPANY, THE. Cleveland, Ohio.

1904. *BROWN, JOHN G. 809 North Forty-first Street, Philadelphia, Pa.

1906. BROWN, RICHARD P. 311 Walnut Street, Philadelphia, Pa.

1904. *BROWN, SAMUEL A. Inspector of Cement, Philadelphia Rapid Transit Company, 812 Sansom Street, Philadelphia, Pa.

1905. BROWN, WM. L. Test Department, Pennsylvania Railroad, Altoona, Pa.

1906. BROWNE, ARTHUR L. Consulting Chemist, 213 Courtland Street, Baltimore, Md.

1903. *BRUNNER, JOHN. Assistant General Superintendent, Illinois Steel Company, 1732 Chicago Avenue, Evanston, Ill.

1905. BUCK, R. S. Consulting Engineer, Department of Bridges, New York, Park Row Building, New York, N. Y.

1903. BUCKLEY, E. R. Director, Missouri Bureau of Geology and Mines, State Geologist, Rolla, Mo.

1905. BUEL, HAMBDEN. V. C. Bogue, 15 William Street, New York, N. Y.

1906. BUFFALO TESTING LABORATORY, George A. Ricker, President, 702 Elliott Square, Buffalo, N. Y.

1904. *BUNNELL, F. O. Engineer of Tests, Chicago, Rock Island and Pacific Railway, Chicago, Ill.

1902. BURDETT, F. A. Civil Engineer, 3 East Thirty-third Street, New York, N. Y.

1906. BURNAP, ARTHUR M. Inspecting and Testing Engineer, 437 Drexel Building, Philadelphia, Pa.

1903. BURNHAM, RAYMOND. Associate Professor of Experimental Engineering, Armour Institute of Technology, Chicago, Ill.

1899. *BURR, WILLIAM H. Professor of Civil Engineering, Columbia University, New York, N. Y.

1906. *BUSH, HAROLD M. Mechanical Engineer, 215 New Hayden Building, Columbus, Ohio.

1905. BUSS, EDWARD A. Consulting Engineer, 85 Water Street, Boston, Mass.

1903. *BUZZI, P. D. Jefe del Laboratorio de Obras Publicas, Arsenal, Havana, Cuba.

1906. CALMAN AND COMPANY, EMIL. Varnish Manufacturers, 299 Pearl Street, New York, N. Y.

ELECTED.

1904. CAIRNS, EDWARD T. General Agent, The North British and Mercantile Insurance Company, 76 William Street, New York, N. Y.

1902. CAMBIER, JACOB. Chemist, Colorado Fuel and Iron Company, 910 Spruce Street, Pueblo, Colo.

1899. *†CAMBRIA STEEL COMPANY. George E. Thackray, Structural Engineer, Johnstown, Pa.

1903. *CAMPBELL, WILLIAM. Instructor in Metallurgy, School of Mines, Columbia University, New York, N. Y.

1906. CANALS, I. A. Civil Engineer, Post Office Box 436, San Juan, P. R.

1898. CAPP, JOHN A. Engineer, Testing Laboratory, General Electric Company, Schenectady, N. Y.

1906. *CARBON STEEL COMPANY. James Johnson, General Superintendent, Thirty-second and Smallman Streets, Pittsburg, Pa.

1906. CARMODY, JOHN M. Inspector, Ambridge, Pa.

1898. †CARNEGIE STEEL COMPANY. W. A. Bostwick, Metallurgical Engineer, Pittsburg, Pa.

1903. *CARNEY, F. D. Assistant Superintendent, The Pennsylvania Steel Company, Steelton, Pa.

1902. CARPENTER, LOUIS G. Professor of Civil and Irrigation Engineering, and Director of Experiment Station, Fort Collins, Colo.

1895. CARPENTER, ROLLA C. Professor of Experimental Engineering, Cornell University, 31 Eddy Street, Ithaca, N. Y.

1903. *CARPENTER STEEL COMPANY, THE. George W. Sargent, Metallurgist, Reading, Pa.

1906. CARR, WM. M. Assistant to President, Commonwealth Steel Company, St. Louis, Mo.

1904. CARTER, J. G. U. S. Inspector, Lock No. 6, Trinity River, Bristol, Texas.

1899. CARTER, ROBERT A. President, Monongahela Iron and Steel Company, Box 215, Pittsburg, Pa.

1903. CARTLIDGE, C. H. Bridge Engineer, Chicago, Burlington and Quincy Railroad, 209 Adams Street, Chicago, Ill.

1905. CENTRAL IRON AND COAL COMPANY. J. Lodge, President, Tuscaloosa, Ala.

1902. *†CENTRAL IRON AND STEEL COMPANY. James B. Bailey, Treasurer and General Manager, Harrisburg, Pa.

1906. CHADSEY, STANLEY B. Chemist, International Harvester Company of Canada, Ltd., Hamilton, Ontario, Canada.

ELECTED.

1905. CHAMBERLAIN, PAUL R. 5906 White Avenue, N. E., Cleveland, O.

1905. CHAMPION, E. C. Superintendent, Kansas Portland Cement Company, Iola, Kans.

1904. CHEESEMAN, FRANK P. National Paint Works, Elliot and Cheeseman, 100 William Street, New York, N. Y.

1905. CHRISTIAN, EDMUND. Manager, Norfolk Creosoting Company, Buell, Va.

1898. CHRISTIE, JAMES (*Member of Executive Committee*). Mechanical Engineer, 100 Rochelle Avenue, Wissahickon, Philadelphia, Pa.

1907. CHRISTIE, ALEXANDER J. Engineer of Tests, American Bridge Company, Ambridge, Pa.

1900. *CHURCHILL, CHARLES S. Chief Engineer, Norfolk and Western Railway, Roanoke, Va.

1906. CINCINNATI CHAPTER, AMERICAN INSTITUTE OF ARCHITECTS. A. O. Elzner, Secretary, 136 Ingalls Building, Cincinnati, Ohio.

1905. *CIVIL ENGINEERS' CLUB OF CLEVELAND, THE. Jos. C. Beardsley, Secretary, 718 Caxton Building, Cleveland, O.

1905. CLAPP, WILFRED A. Civil Engineer, United States Quartermaster's Department, 103 Sherman Street, Portland, Me.

1900. *CLARK, F. H. General Superintendent of Motive Power, Chicago, Burlington and Quincy Railroad, 209 Adams Street, Chicago, Ill.

1905. CLARKE, D. D. Civil Engineer, Water Board, City Hall, Portland, Ore.

1905. CLARKE, ST. JOHN. Chief Engineer, New York and Long Island Railroad, 16 East Forty-second Street, New York, N. Y.

1904. CLARKSON MEMORIAL SCHOOL OF TECHNOLOGY, THOMAS S. William S. Aldrich, Director, Potsdam, N. Y.

1905. CLEMENTS, FRANK O. Chemist, National Cash Register Company, Dayton, Ohio.

1904. CLIFTON, CHARLES H. First Assistant, Philadelphia Municipal Testing Laboratory, 318 City Hall, Philadelphia, Pa.

1905. COE, EDWARD K. Assistant City Engineer, 1411 East Third Street, Duluth, Minn.

1899. COLBY, ALBERT LADD. 217 West One Hundred and Tenth Street, New York, N. Y.

ELECTED.

1899. COLBY, J. ALLEN. Inspecting Engineer, Witherspoon Building, Philadelphia, Pa.

1904. COLLES, GEORGE W. Consulting Mechanical and Electrical Engineer, 408 Alhambra Building, Milwaukee, Wis

1900. *COLORADO FUEL AND IRON COMPANY. C. S. Robinson, General Manager, Iron Department, Denver, Colo.

1905. CONDIT, E. A., JR. Inspector, Continuous Rail Joint Company, 520 Summer Avenue, Newark, N. J.

1905. CONDIT, FILLMORE. Manager, California Asphaltum Sales Agency, 11 Broadway, New York, N. Y.

1900. CONDRON, T. L. Consulting Engineer, 1442 Monadnock Building, Chicago, Ill.

1904. CONLIN, FREDERICK. General Manager, Bethlehem Foundry and Machine Company, Lehigh Foundry Company, 355 Market Street, Bethlehem, Pa.

1904. CONNOR, CHARLES E. Assistant Inspector of Buildings of District of Columbia, The Farragut, Washington, D. C.

1906. CONOVER, H. SPENCER. Cement Inspector, Cementon, Pa.

1904. CONRADSON, P. H. Chief Chemist, Galena Signal Oil Company, Franklin, Pa.

1905. CONVERSE, W. A. Directing Chemist, Dearborn Drug and Chemical Works, 227–234 Rialto Building, Chicago, Ill.

1906. COOK, D. S. Superintendent, Speed Mills, Louisville Cement Company, Sellersburg, Ind.

1903. COOK, EDGAR S. President, Warwick Iron and Steel Company, Pottstown, Pa.

1906. *CORNELL UNIVERSITY LIBRARY. George W. Harris, Librarian, Ithaca, N. Y.

1899. *CORTHELL, E. L. Civil Engineer, 1 Nassau Street, New York, N. Y.

1902. COSBY, SPENCER. Captain, Corps of Engineers, United States Army, care of War Department, Washington, D. C.

1906. *COWAN, GEORGE P. Assistant Engineer, Department of Engineering and Public Works, Manila, P. I.

1903. COWEN, HERMAN C. Superintendent, Catskill Cement Company, Smith Landing, Greene County, N. Y.

1906. CRAWFORD, D. F. General Superintendent, Motive Power, Pennsylvania Railroad Lines West, Room 1106, Union Station, Pittsburg, Pa.

1905. CRAWFORD, HARRY C. Inspector, Railway Equipments, Fox Chase, Philadelphia, Pa.

ELECTED.

1906. CROMWELL, O. C. Mechanical Engineer, Baltimore and Ohio Railroad Company, Mount Clare, Baltimore, Md.

1907. CROSS, WALTER M. City Chemist, City Hall, Kansas City, Mo.

1904. *CROWELL, BENEDICT. Mining Engineer, 731 Williamson Building, Cleveland, O.

1903. CROXTON, H. A. President, Massillon Iron and Steel Company, Massillon, O.

1899. *CRUIKSHANK, BARTON. The Solway Process Company, Syracuse, N. Y.

1904. CUMMINGS, ROBERT A. Consulting and Contracting Engineer, 4 Smithfield Street, Pittsburg, Pa.

1906. *CUSHING, W. C. Chief Engineer, Maintenance of Way, Pennsylvania Lines, South West System, Union Station, Pittsburg, Pa.

1904. CUSHMAN, ALLERTON S. Chemist, Road Material Laboratory, United States Department of Agriculture, Washington, D. C.

1903. DABBS, HAROLD M. L. J. McCloskey and Company, Thirtieth and Locust Streets, Philadelphia, Pa.

1906. DAMON, GEORGE A. Managing Engineer, The Arnold Company, Borland Building, Chicago, Ill.

1900. *DAVIDSON, GEORGE M. Engineer of Tests, Chicago and Northwestern Railroad, Chicago, Ill.

1904. DAVIS, A. P. Assistant Chief Engineer, United States Geological Survey, Washington, D. C.

1904. *DAVIS, CHANDLER. Department of Docks and Ferries, Pier "A," North River, New York, N. Y.

1905. DAVIS, CHARLES HENRY. 25 Broad Street, New York, N. Y.

1906. DAVIS, J. C. Assistant First Vice-President, American Steel Foundries, Chicago, Ill.

1904. DAVIS, NATHAN H. President, Diamond State Car Steel Company, Davis Pressed Steel Company, Wilmington, Del.

1903. *DAVIS, WILLIAM R. Chief Bridge Designer, State Engineer's Office, Albany, N. Y.

1904. DAVIS, WILLIAM M. Oil Inspector, in Charge of Lubrication, American Sheet and Tin Plate Company, Sheridanville, Allegheny County, Pa.

1902. *DE ARMOND, W. C. President, Protectus Company, 1103 North American Building, Philadelphia, Pa.

ELECTED.

1906. *DECEW, J. A. Consulting Chemical Engineer, Sun Life Building, Montreal, Canada.

1905. *DEKNIGHT, EDWARD W. President and Manager, Hydrex Felt and Engineering Company, 120 Liberty Street, New York, N. Y.

1906. *DEROODE, RUDOLF. Superintendent, Bureau of Tests, International Paper Company, Glens Falls, N. Y.

1905. DEWOLF, R. D. Electrical Engineer, Westinghouse Electric and Manufacturing Company, 508 Rebecca Street, Wilkinsburg, Pa.

1904. DE WYRALL, CYRIL. Chief Inspector, Interborough Rapid Transit Company, New York City. *For Mail*, Ridgefield Park, N. J.

1899. *DEANS, JOHN STERLING. Chief Engineer, Phœnix Bridge Company, Phœnixville, Pa.

1906. DENNIS, D. B. The Patterson, Sargent Company, 42 Hudson Street, New York, N. Y.

1906. DEPARTMENT OF CIVIL ENGINEERING, CASE SCHOOL OF APPLIED SCIENCE. F. H. Neff, Professor of Civil Engineering, Cleveland, Ohio.

1904. DEPARTMENT OF ENGINEERING, TUFTS COLLEGE. Gardner C. Anthony, Dean, Tufts College, Mass.

1902. DERLETH, CHARLES, JR. Professor of Structural Engineering, University of California, Berkeley, Cal.

1904. DETROIT GRAPHITE MANUFACTURING COMPANY. F. W. Davis, Jr., Second Vice-President, 141 Broadway, New York, N. Y.

1903. DEVERELL, H. F. Secretary, Otis Steel Company, Cleveland, O.

1905. DICKERSON, W. H. Assistant Engineer of Tests, Union Pacific Railroad, 3708 North Twenty-first Street, Omaha, Neb.

1903. *DIEDERICHS, H. Assistant Professor of Experimental Engineering, Cornell University, 913 North Aurora Street, Ithaca, N. Y.

1903. DILLER, H. E. Chemist, Hawthorne Engineering Laboratories, Western Electric Company, Chicago, Ill.

1904. DINAN, EDWARD. Chemist, Edison Portland Cement Company, 230 East Third Street, South Bethlehem, Pa.

1902. DIXON CRUCIBLE COMPANY, JOSEPH. Malcolm McNaughton, Superintendent, Paint and Lubricating Department, Jersey City, N. J.

ELECTED.

1903. †DIXON, R. M. Vice-President, The Safety Car Heating and Lighting Company, 160 Broadway, New York, N. Y.

1901. *DOBLE, WILLIAM A. President, Abner Doble Company, Seventh and South Streets, San Francisco, Cal.

1904. DOMINION BRIDGE COMPANY. Phelps Johnson, Manager, Montreal, Canada.

1905. *DONOHOE, JOHN P. Vice-President and General Manager, Donohoe Coke Company, Greensburg, Pa.

1906. DOUTY, D. E. Assistant Physicist, Bureau of Standards, Washington, D. C.

1898. *DOW, ALLAN W. 120 East Twenty-third Street, New York N. Y.

1903. DRAKE, C. F. Western Manager, Crowell, Dickman and Kenyon, Inspecting Engineers, 1120 Rookery Building, Chicago, Ill.

1903. DRUMMOND, M. J. President, Glamorgan Pipe and Foundry Company, 192 Broadway, New York, N. Y.

1905. DUBBS, C. P. General Manager, Globe Asphalt Company, 310 Togo Building, Los Angeles, Cal.

1904. DUBBS, J. A. President, Globe Asphalt Company, 405 Bakewell Building, Pittsburg, Pa.

1902. DU COMB, W. C., JR. Davis Pressed Steel Company, Wilmington, Del.

1896. *†DUDLEY, CHARLES B. (*President*). Chemist, Pennsylvania Railroad, Altoona, Pa.

1902. DUDLEY, P. H. Consulting Engineer, 80 Pine Street, New York, N. Y.

1906. DUERR, H. O. General Manager, Diamond Stone Brick Company, Box 261, Wilmington, Del.

1901. DUFOUR, F. O. Assistant Professor of Structural Engineering, University of Illinois, Urbana, Ill.

1902. DUMARY, L. HENRY. President, The Helderberg Cement Company, 38 State Street, Albany, N. Y.

1902. DUNBAR, W. O. Assistant Engineer, Testing Department, Pennsylvania Railroad, Altoona, Pa.

1904. DUNN, W. R. Superintendent, Vulcanite Portland Cement Company, Phillipsburg, N. J.

1905. DUNNING, HUBERT. National Lead Company, 100 William Street, New York, N. Y.

1904. DURYEE, E. Cement Expert, United States Reclamation Service, Roosevelt, Ariz.

ELECTED.

1904. DWIGHT, THEODORE. Electrical Engineer, Post Office Box 223, New York, N. Y.

1905. EAGLE WHITE LEAD COMPANY. F. J. Baringer, Chemist, Cincinnati, O.

1902. EASBY, M. WARD. Consulting Engineer, 909 Crozer Building, Philadelphia, Pa.

1906. EASTERBROOKS, FRANK D. Chemical Engineer, Perth Amboy, N. J.

1905. EATON, LEWIS G. Sandusky Portland Cement Company, Syracuse, Ind.

1905. EDGERLY, DANIEL W. Manager, Chilton Paint Company, 120 High Street, Boston, Mass.

1902. EDWARDS, WARRICK R. Assistant Engineer, Baltimore and Ohio Railroad, Baltimore and Ohio Building, Baltimore, Md.

1905. *EHRENFELD, CHARLES H. Chemist, York Manufacturing Company, York, Pa.

1904. *EIDLITZ, OTTO M. Civil Engineer, 489 Fifth Avenue, New York, N. Y.

1903. ELDRIDGE, G. F. B. Nicoll and Company, 59 Wall Street, New York, N. Y.

1905. ELLIS, THEODORE H. President, The Ellis Company, 641 Calvert Building, Baltimore, Md.

1896. *ELY, THEODORE N. Chief of Motive Power, Pennsylvania Railroad, Broad Street Station, Philadelphia, Pa.

1905. ELZNER, A. O. Architect, 136 Ingalls Building, Cincinnati, O.

1905. EMERSON, GEORGE H. Vice-President, North Western Lumber Company, Hoquiam, Wash.

1898. ENGINEERING RECORD. 114 Liberty Street, New York, N. Y.

1905. ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA. F. V. McMullin, Secretary, 803 Fulton Building, Pittsburg, Pa.

1905. ENGINEERS' CLUB OF CINCINNATI. E. A. Cast, Secretary-Treasurer, Post Office Box 333, Cincinnati, O.

1905. ENRIGHT, BERNARD. Chief Chemist, Virginia Portland Cement Company, Fordwick, Augusta County, Va.

1903. *ERLANDSEN, OSCAR. Chief Engineer, O'Rourke Engineering Construction Company, 1 West Thirty-fourth Street, New York, N. Y.

ELECTED.

1903. ESTERLINE, J. WALTER. Assistant Professor of Electrical Engineering, Purdue University, Lafayette, Ind.

1905. *ESTILL, HOWARD S. Assistant Engineer, Chesapeake and Ohio Railway, Richmond, Va.

1905. EVANS, D. T. General Manager, The Mount Carbon Company, Limited, Powellton, W. Va.

1906. EVANS, R. W. Treasurer, Picher Lead Company, 511 Tacoma Building, Chicago, Ill.

1904. EVANS, S. M. Manager New York Office, Picher Lead Company, 100 William Street, New York, N. Y.

1904. EWEN, JOHN M. Vice-President, Thompson-Starrett Company, 1402 Railway Exchange, Chicago, Ill.

1905. EWING, W. W. Engineer, Westinghouse, Church, Kerr and Company, 10 Bridge Street, New York, N. Y.

1904. *FACKENTHAL, JR., B. F. President, Thomas Iron Company, Easton, Pa.

1903. FACULTY APPLIED SCIENCE, MCGILL UNIVERSITY. Henry T. Bovey, Dean, Montreal, Can.

1905. FALK, MYRON S. Instructor in Civil Engineering, Columbia University, 44 West Fifty-third Street, New York, N. Y.

1902. FALKENAU, A. 919 Witherspoon Building, Philadelphia Pa.

1902. FARREL FOUNDRY AND MACHINE COMPANY. Walter Perry, Manager, Foundry Department, Ansonia, Conn.

1902. FAY, HENRY. Associate Professor of Analytical Chemistry and Metallography, Massachusetts Institute of Technology, Boston, Mass.

1903. FENNER, L. M. Chemical Engineer, H. H. Franklin Manufacturing Company, 342½ Delaware Street, Syracuse, N. Y.

1905. FERNOW, B. E. Consulting Forest Engineer, 42 Broadway, New York, N. Y.

1906. FINDLEY, A. I. Editor, *The Iron Age*, 14 Park Place, New York, N. Y.

1905. *FINN, GEORGE H. General Manager, The New England Gas and Coke Company, Old South Building, Boston, Mass.

1903. FITZ GERALD, FRANCIS A. J. Chemical Engineer, Fitz Gerald and Bennie Laboratories, Niagara Falls, N. Y.

1899. FLAGG, STANLEY G., JR. Stanley G. Flagg and Company, Nineteenth Street and Pennsylvania Avenue, Philadelphia, Pa.

ELECTED.

1904. *FLEMING, HENRY S. Consulting Engineer, 1 Broadway, New York, N. Y.

1906. FOLLER, CHARLES S. Mechanical Engineer, Union Spring Manufacturing Company, Farmers Bank Building, Pittsburg, Pa.

1904. FORD, ALLEN P. Metallurgist, Eaton, Cole and Burnham Company, Bridgeport, Conn.

1901. FORREST, C. N. Chief Chemist, New York Testing Laboratory, Long Island City, N. Y.

1903. FORSYTH, WILLIAM. Mechanical Engineer, *Railway Age*, Chicago, Ill.

1906. FOSTER, H. W. Steel Inspector, Bethlehem Steel Company, South Bethlehem, Pa.

1904. FOSTER, W. C. Vice-President and General Manager, Glamorgan Pipe and Foundry Company, 182 Broadway, New York, N. Y.

1905. FOX, ADAM H. Superintendent, Forge Department, American Bridge Company, 233 Rochelle Avenue, Wissahickon, Philadelphia, Pa.

1906. FRANK JEROME W. Chemist, Standard Varnish Works, 29 Broadway, New York, N. Y.

1898. FRANKLIN INSTITUTE. William H. Wahl, Secretary, 15 South Seventh Street, Philadelphia, Pa.

1905. *FRAZIER, H. Consulting Engineer, Seaboard Air Line Railway, 812 American Bank Building, Richmond, Va.

1905. *FREEMAN, JOHN R. Consulting Engineer, 815 Barrigan Building, Providence, R. I.

1903. FRENCH, JAMES B. Bridge Engineer, The Long Island Railroad Company, Jamaica, N. Y.

1904. FROEHLING AND ROBERTSON. Analytical Chemists, Chemical and Mining Engineers, 17 South Twelfth Street, Richmond, Va.

1905. *FRY, LAWFORD H. Engineer of Tests, Baldwin Locomotive Works, 500 North Broad Street, Philadelphia, Pa.

1903. *FULLER, ALMON H. Professor of Civil Engineering, Washington University, University Station, Seattle, Wash.

1906. FULLER, CHARLES E. Associate Professor of Mechanical Engineering, Massachusetts Institute of Technology, Boston, Mass.

1904. FULLER, WM. B. Consulting Civil Engineer, 170 Broadway, New York, N. Y.

ELECTED.

1905. *GAEHR, DAVID. 683 Gordon Avenue, Cleveland, O.

1903. GALBRAITH, J. Principal, School of Practical Science, Toronto, Can.

1905. GARFIELD, ALEXANDER STANLEY. Chief Engineer, Cie. Francaise Thomson-Houston; Consulting Engineer, Mediterranean Thomson-Houston Company and General Electric Company. 67 Avenue De Malakoff, Paris, France.

1905. GARLINGHOUSE, F. L. Structural Engineer, Jones and Laughlin Steel Company, Glenshaw, Pa.

1905. GAY, MARTIN. Assistant Engineer, Department of Bridges, New York City, 103 East One Hundred and Twenty-fifth Street, New York, N. Y.

1905. GERLACH, O. General Superintendent, Iola Portland Cement Company, Iola, Kan.

1902. *GERSTELL, A. F. Vice-President and General Manager, Alpha Portland Cement Company, Alpha, N. J.

1906. GIBBONEY, JAMES H. Chief Chemist, Norfolk and Western Railway Company, 342 Campbell Avenue, S. W., Roanoke, Va.

1902. GIBBS, A. W. General Superintendent of Motive Power, Pennsylvania Railroad, Altoona, Pa.

1902. *GIBBS, GEORGE. First Vice-President, Westinghouse, Church, Kerr and Company, 10 Bridge Street, New York, N. Y.

1905. GIESLER, ARTHUR. Consulting Engineer, 29 Broadway, New York, N. Y.

1905. GILBERT H. GRAY. Assistant Engineer, Chief Engineer's Office, Louisville and Nashville Railroad, Louisville, Ky.

1907. GILG, HENRY F. Secretary, Refined Iron and Steel Company, 606 Lewis Building, Pittsburg, Pa.

1905. GILL, AUGUSTUS H. Assistant Professor of Technical Analysis, Massachusetts Institute of Technology, Boston, Mass.

1906. GILLESPIE, ARTHUR J. Representative, The Patterson, Sargent Company, 4929 Forrestville Avenue, Chicago, Ill.

1906. GINDER, WM. H. H. Chemist and Engineer of Tests, Eastern Steel Company, Pottsville, Schuylkill County, Pa.

1904. *GIROUX, GUSTAVE. Inspector of Materials, Canadian Pacific Railway Company, 1101 East Craig Street, Montreal, P. Q., Canada.

ELECTED.

1904. *GLASGOW IRON COMPANY. C. B. Shoemaker, President, 603-608 Harrison Building, Philadelphia, Pa.

1904. *GODWIN, W. S. General Manager, American Block Press Company, 404 Temple Bar Building, Brooklyn, N. Y.

1904. GOODMAN, CARLTON M. Superintendent, Standard Portland Cement Company, Leeds, Ala.

1904. GOODSPEED, G. M. Meallurgist, National Tube Company, McKeesport, Pa.

1904. GOODWIN, H. S. Bridge Inspector, 201 North Owen Avenue, Lansdowne, Pa.

1896. GOSS, WILLIAM, F. M. Dean of the Schools of Engineering, Purdue University, Lafayette, Ind.

1905. GOW, CHARLES R. Civil Engineer and Contractor, 79 Milk Street, Boston, Mass.

1904. GOWEN, CHARLES S. Engineer, New Croton Dam, Ossining, N. Y.

1906. *GRACE, S. P. Chief Engineer, Central District and Printing Telegraph Company, Pittsburg, Pa.

1903. GRANTHAM, HERBERT T. Chief Engineer, Belmont Iron Works, 1622 Real Estate Trust Building, Philadelphia, Pa.

1906. GRAY, JR., JOHN H. Chemist to the Board of Public Works, 2511 Sacramento Street, San Francisco, Cal.

1903. GRAY, JOHN LATHROP. Assistant Superintendent, Tidewater Oil Company, East Twenty-second Street, Bayonne, N. J.

1896. *GRAY, THOMAS. Professor of Dynamic Engineering, Rose Polytechnic Institute, Terre Haute, Ind.

1905. *GRAY, THOMAS TARVIN. Chemist, Tide Water Oil Company, East Twenty-second Street, Bayonne, N. J.

1906. GREEN, HERBERT. Mechanical Engineer, South Baltimore Steel Car and Foundry Company, Baltimore Md.

1906. GREENE, FREDERICK S. Vice-President and General Manager, The Waterproofing Company, 151 West Twenty-eighth Street, New York, N. Y.

1905. GREENE, GEO. W. Inspecting Engineer, American Bureau of Inspection and Tests, Heeren Building, Eighth and Penn Avenue, Pittsburg, Pa.

1904. *GREENMAN RUSSELL S. Assistant Engineer, State Engineer's Department, Albany, N. Y.

1906. GREGORY, ED. D. Mill Manager, Frazer Paint Company, Bedford City, Va.

ELECTED.

1906. GREGORY, JOHN H. Engineer in Charge, Improved Water and Sewage Works, Columbus, O.

1904. *GREGORY, W. B. Associate Professor of Experimental Engineering, Tulane University of Louisiana, New Orleans, La.

1902. GREINER, J. E. Assistant Chief Engineer, Baltimore and Ohio Railroad, Baltimore, Md.

1907. GRIESENAUER, GEORGE J. Cement Tester, Chicago, Milwaukee and St. Paul Railway Company, 194 Fullerton Avenue, Chicago, Ill.

1906. GRIFFITH, R. E. Vice-President, American Cement Company, 604 Pennsylvania Building, Philadelphia, Pa.

1906. *GRIFFITHS, T. S. General Manager, Canadian Inspection Company, St. James Street, Montreal, Can.

1905. GRISWOLD, R. E. 108 Vine Street, Batavia, N. Y.

1906. GROSSMANN, EDMUND. Chief Engineer, Unit Concrete Steel Frame Company, Philadelphia, Pa. 62 Throop Avenue, Brooklyn, N. Y.

1904. GUPPY, BENJ. W. Bridge Engineer, Maine Central Railroad, 238 St. John Street, Portland, Maine.

1906. *HADFIELD, R. A. Steel Manufacturer, Hecla Works, Sheffield, England.

1901. HAGAR, EDWARD M. Manager, Cement Department, Illinois Steel Company, 1060 The Rookery, Chicago, Ill.

1906. HAINES, JOHN L. Chief of Order Department, Jones and Laughlin Steel Company, Pittsburg, Pa.

1905. HALDEMAN, HORACE L. Treasurer, Pulaski Iron Company, 1008 Real Estate Trust Building, Philadelphia, Pa.

1905. HALL, WILLIAM L. Assistant Forester, in Charge of Office of Forest Products, Bureau of Forestry, United States Department of Agriculture, Washington, D. C.

1903. *HALLETT, NELSON A. Cement Inspector, 1 Ashburton Place, Boston, Mass.

1906. HAM, WILLIAM H. Engineer, General Fireproofing Company, 156 Fifth Avenue, New York, N. Y.

1905. HAMILTON, M. C. Assistant Engineer of Construction, New York, New Haven and Hudson River Railroad, 139 Sigourney Street, Hartford, Conn.

1903. *HANCOCK, E. L. Assistant Professor of Applied Mechanics, Purdue University, Lafayette, Ind.

1905. *HAND, ELWOOD STOKES. Installation Engineer, Mississippi Wire Glass Company, 277 Broadway, New York, N. Y.

ELECTED

1905. HANNA, W. C. Chemist, California Portland Cement Company, Colton, Cal.

1905. HARDING, CHESTER. Captain, Corps of Engineers, United States Army, District Building, Washington, D. C.

1904. *HARDING, JAMES J. Engineer of Masonry Construction, Chicago, Milwaukee and St. Paul Railway, 1232 Railway Exchange Building, Chicago, Ill.

1902. HARDING, W. H. President, Bonneville Portland Cement Company, 2029 Land Title Building, Philadelphia, Pa.

1903. *HARGROVE, JULIAN O. Assistant Inspector of Asphalt and Cement, 1603 O Street, N. W., Washington, D. C.

1902. HARRIMAN, N. F. Chemist and Engineer of Tests, Union Pacific Railroad, Omaha, Neb.

1905. HARRISON, ARTHUR B. Manager, Paint Department, Clifford L. Miller and Company, 125 East Twenty-third Street, New York, N. Y.

1902. *HARTFORD STEAM BOILER INSPECTION AND INSURANCE COMPANY. Francis B. Allen, Vice-President, Hartford, Conn.

1904. HARTLEY, HENRY J. Superintendent, Boiler Department, William Cramp and Sons, 1624 Oxford Street, Philadelphia.

1898. HARTRANFT CEMENT COMPANY, WILLIAM G. Sole Selling Agent for Old Dominion and Phœnix Portland Cement, Real Estate Trust Building, Philadelphia, Pa.

1905. *HARVARD COLLEGE LIBRARY. Alfred C. Potter, Assistant Librarian, Cambridge, Mass.

1898. *HATT, WILLIAM K. Professor of Applied Mechanics, Purdue University, Lafayette, Ind.

1904. HAWXHURST, ROBERT. Consulting Engineer, 10 Austin Friars, London, E. C., England.

1906. HAYES, J. ARTHUR. Resident Manager, United States Cast Iron Pipe and Foundry Company, Burlington, N. J.

1904. *HAYES, HAMMOND V. Engineer, American Telephone and Telegraph Company, 125 Milk Street, Boston, Mass.

1906. *HAYWARD, H. W. Instructor, Mechanical Engineering, Massachusetts Institute of Technology, Boston, Mass.

1906. HAZARD MANUFACTURING COMPANY. John C. Bridgman, General Manager, Wilkesbarre, Pa.

1906. HEALD, E. C. Chief Structural Engineer, Office of Supervising Architect, Treasury Department, Washington, D. C.

ELECTED.

1903. HEARNE, W. W. Member of firm Mathew Addy and Company, 1625 Real Estate Trust Building, Philadelphia, Pa.

1905. HECKEL, G. B. Editor, *Drugs, Oils and Paints*, 634–36 The Bourse, Philadelphia, Pa.

1904. HEIDENREICH, E. LEE. Consulting Engineer, General Supply and Construction Company, 24 State Street, New York, N. Y.

1904. *HELWIG, ALFRED. Engineer, Edison Electric Illuminating Company, 360 Pearl Street, Brooklyn, N. Y.

1904. *HEMSTREET, GEORGE P. Superintendent, Hastings Pavement Company, Hastings-on-Hudson, N. Y.

1903. HENSHAW, JOHN O. Member, N. S. Bartlett and Company, 126 State Street, Boston, Mass.

1904. *HERING, RUDOLPH. Hydraulic and Sanitary Engineer, 170 Broadway, New York, N. Y.

1906. HERNDON, EDWARD L. Treasurer, The Eastern Steel Company, Pottsville, Pa.

1906. *HERSEY, MILTON L. City and Provincial Analyst, 171 St. James Street, Montreal, Canada.

1902. HILDRETH, P. S. Consulting and Inspecting Engineer, 32 Broadway, New York, N. Y.

1905. HITCHCOCK, F. C. Engineer, Contractor and Manufacturer, Room 205, 253 Broadway, New York, N. Y.

1906. HOBBS, F. E. Major, Ordnance Department, U. S. Army, Watertown Arsenal, Watertown, Mass.

1904. *HOFF, OLAF. Vice-President, Butler Brothers Construction Company, 1170 Broadway, New York, N. Y.

1902. HOFMAN, H. O. Professor of Metallurgy, Massachusetts Institute of Technology, Boston, Mass.

1906. HOLMES, ADDISON F. Instructor, Mechanical Engineering, Massachusetts Institute of Technology, Boston, Mass.

1903. HOLMES, JOSEPH A. State Geologist of North Carolina, Chapel Hill, N. C.

1906. *HOOKER, A. H. Chief Chemist, The Heath and Milligan Manufacturing Company, 90 Seward Street, Chicago, Ill.

1904. HOPTON, W. E. Assistant Purchasing Engineer, Solvay Process Company, Syracuse, N. Y.

1904. HOW, R. W. Chief Inspector, Bridge Engineer's Office, Long Island Railroad Company, 5 Hanson Place, Brooklyn, N. Y.

ELECTED.

1906. HOWARD, JAMES E. Watertown Arsenal, Watertown, Mass.

1903. HOWARD, L. E. Superintendent, Simonds Manufacturing Company, Seventeenth Street and Western Avenue, Chicago, Ill.

1896. *HOWE, HENRY M. (*Past-President*). Professor of Metallurgy, Columbia University, 27 West Seventy-third Street, New York, N. Y.

1904. *HUBBELL, C. A. President, R. Almond Manufacturing Company, Brooklyn, N. Y.

1904. HUBER, FREDERICK W. Engineer of Tests, United States Geological Survey, Berkeley, Cal.

1905. *HUDSON, H. N. General Manager, Hoyt Metal Company, St. Louis, Mo.

1906. HUGHES, E. A. Secretary, Moorhead Brother and Company, Sharpsburg, Pa.

1905. *HUGHES, HECTOR J. Assistant Professor of Hydraulics and Sanitary Engineering, Harvard University, 114 Pierce Hall, Cambridge, Mass.

1905. HUGHES AND PATTERSON. Manufacturers of Bar Iron, 800 Richmond Street, Philadelphia, Pa.

1904. HUME, A. P. Engineer of Tests, American Bridge Company, Pencoyd, Pa.

1896. *HUMPHREY, RICHARD L. Consulting Engineer and Chemist, 1001 Harrison Building, Philadelphia, Pa.

1906. HUMPTON, WM. G. Engineer of Tests, Cambria Steel Company, 408 Napoleon Street, Johnstown, Pa.

1903. HUNNINGS, S. V. Chief Chemist, American Locomotive Company, Schenectady, N. Y.

1905. HUNT, H. B. General Inspector, American Locomotive Company, Schenectady, N. Y.

1903. *HUNT, LOREN E. Civil Engineer, United States Forest Service, Berkeley, Cal.

1899. *HUNT COMPANY, ROBERT W. Inspecting and Testing Engineers, 1121 The Rookery, Chicago, Ill.

1905. HUNTER, JOHN ANDREW. Assistant Professor of Mechanical Engineering, University of Colorado, Boulder, Col.

1903. HUNTER, JOSEPH W. Engineer and Surveyor, State Highway Commissioner, Harrisburg, Pa.

1906. HUTCHINSON, CARY T. Consulting Engineer, 60 Wall Street, New York, N. Y.

ELECTED.

1904. HUTCHINSON, GEORGE W. Engineer of Tests, Old Dominion Iron and Nail Works, Richmond, Va.

1905. HYDE, A. LINCOLN. Assistant Professor of Bridge Engineering, University of Missouri, Columbia, Mo.

1903. HYDE, CHARLES G. Assistant Professor of Sanitary Engineering, University of California, Berkeley, Cal.

1906. ICKES, ELWOOD T. Inspector, Carnegie Steel Company, Room 522, Carnegie Building, Pittsburg, Pa.

1904. *†ILLINOIS CENTRAL RAILROAD COMPANY, J. T. Harahan, Second Vice-President, Chicago, Ill.

1900. †ILLINOIS STEEL COMPANY. P. E. Carhart, Inspecting Engineer, Rookery Building, Chicago, Ill.

1906. INGALLS, F. P. Chemist, John W. Masury and Son, 1329 Fiftieth Street, Brooklyn, N. Y.

1903. INSURANCE ENGINEERING. Franklin Webster, Editor, 120 Liberty Street, New York, N. Y.

1902. INTERNATIONAL ACHESON GRAPHITE COMPANY. Manufacturers of Graphite and Graphite Articles, Niagara Falls, N. Y.

1904. INTERNATIONAL HARVESTER COMPANY. John G. Wood, Second Assistant Manager, Manufacturing Department, 7 Monroe Street, Chicago, Ill.

1902. IRON TRADE REVIEW, THE. Robert T. Kent, Editor, Cleveland, O.

1906. IRWIN, J. F. Chemist, Williamsburg, Pa.

1896. JARECKI, ALEXANDER. Superintendent, Jarecki Manufacturing Company, Limited, Erie, Pa.

1905. JEFFERS, JOHN M. Oil Inspector, National Tube Company, 1603 Jenny Lind Street, McKeesport, Pa.

1905. JENKINS, FREDERICK E. Vice-President, Round Top Cement Company, Hancock, Md.

1897. JENKINS, JOHN. General Manager, Milton Iron Company Milton, Pa.

1904. JENNINGS, ARTHUR S. Editor, *The Decorator*, 365 Birkbeck Bank Chambers, High Holborn, London, W. C., England.

1906. JENNINGS, BERTRAND F. Manager, Hudson Portland Cement Company, 161 Devonshire Street, Boston, Mass.

1900. *JEWETT, J. Y. Cement Expert, Reclamation Service, United States Geological Survey, Denver, Col.

ELECTED.

1900. JOB, ROBERT, Member of firm Booth, Garrett and Blair, 406 Locust Street, Philadelphia, Pa.

1903. *JOHNSON, ALBERT L. Chief Engineer, Expanded Metal Fire-proofing Company, 606 Century Building, St. Louis, Mo.

1903. *JOHNSON, ARTHUR N. State Highway Engineer, Springfield, Ill.

1904. JOHNSON, CHARLES C. Chemist, Standard Explosives Company, Ltd., Vandreuil Station, Quebec, Canada.

1905. *JOHNSON, EDMUND. Cement Chemist, Yankton, S. Dak.

1904. JOHNSON, J. S. A. In charge of Testing Laboratory, Virginia Polytechnic Institute, Blacksburg, Va.

1904. JOHNSON, LEWIS J. Professor of Civil Engineering, Harvard University, 309 Pierce Hall, Cambridge, Mass.

1900. *JOHNSON, WALLACE C. Consulting Engineer, Niagara Falls, N. Y.

1904. JOHNSON, W. MARTIN. Vice-President, The Schoen Steel Wheel Company, 312 South Fifteenth Street, Philadelphia, Pa.

1906. JOHNSTON, W. C. Manager, Iron Mill, Monongahela Iron and Steel Company, Post Office Box 215, Pittsburg, Pa.

1906. JOHNSTON, WILLIAM A. Associate Professor of Mechanical Engineering, Massachusetts Institute of Technology, Boston, Mass.

1905. *JONES, C. R. Professor of Mechanical Engineering, West Virginia University, Morgantown, W. Va.

1902. *†JONES AND LAUGHLIN STEEL COMPANY. Steel Manufacturers; Willis L. King, Vice-President, Pittsburg, Pa.

1903. JORDAN, WILLIAM, JR. Structural Materials Testing Laboratory, U. S. Geological Survey, St. Louis, Mo.

1906. KAFKA, FRED P. Civil Engineer, 1133 Broadway, New York, N. Y.

1906. KANSKI, ROMAN P. Topographical Draughtsman, Office of President of Borough of Bronx, 607 Union Avenue, New York, N. Y.

1904. KASSON, HENRY R. District Manager, Barber Asphalt Paving Company, 1236 Stock Exchange Building, Chicago, Ill.

1906. *KAUFMAN, GUSTAVE. Chief Engineer, The Wilson and Baillie Manufacturing Company, 26 Court Street, Brooklyn, N. Y.

ELECTED.

1904. *KAY, EDGAR B. Professor of Engineering, University of Alabama, University Post Office, Ala.

1906. KEARNS, W. F. 161 Devonshire Street, Boston, Mass.

1903. KEAY, H. O. Assistant Professor of Mechanical Engineering, McGill University, Montreal, Canada.

1906. KELLOGG, R. S. Forest Assistant, Forest Service, Washington, D. C.

1899. KENNEDY, FRANK G., JR. 408 North American Building, Philadelphia, Pa.

1904. *KENNEDY, JEREMIAH J. Consulting Engineer, 52 Broadway, New York, N. Y.

1904. KENNEY, E. F. Engineer of Tests, Pennsylvania Railroad Company, Broad Street Station, Philadelphia, Pa.

1906. KENNEY, LEWIS HOBART. Inspecting Draftsman, Bureau of Steam Engineering, U. S. Navy, 4226 Girard Avenue, Philadelphia, Pa.

1902. KENT, WILLIAM. Professor of Mechanical Engineering, and Dean of the L. C. Smith College of Applied Science, Syracuse University, Syracuse, N. Y.

1904. KENYON, CLARENCE A. President, Hoosier Construction Company and Granite Bituminous Paving Company, Indianapolis, Ind.

1905. KETCHUM, MILO S. Professor of Civil Engineering, University of Colorado, Boulder, Col.

1903. KIESEL, W. F., JR. Assistant Mechanical Engineer, Pennsylvania Railroad, Altoona, Pa.

1906. *KIMMEL, H. R. Chemist, Studebaker Brothers Manufacturing Company, The Duey—D, South Bend, Ind.

1905. KING, W. GRANT. Manager, Iroquois Iron Works, 178 Walden Avenue, Buffalo, N. Y.

1899. *KING, WILLIS L. Vice-President, Jones and Laughlin Steel Company, Pittsburg, Pa.

1899. *KINKEAD, J. A. Engineer of Tests, American Locomotive Company, Schenectady, N. Y.

1902. *KIRCHHOFF, C. Editor, *The Iron Age*, 14 Park Place, New York, N, Y.

1903. *KIRCHNER, PAUL A. Engineer of Bridges, New York, West Chester and Boston Railway Company, 30 Broad Street, New York, N. Y.

1903. *KITTREDGE, H. G. Secretary, The Kay and Ess Company, Dayton, O.

ELECTED.

1905. KLINGER, P. W. Assistant Superintendent, Barney and Smith Car Company, 236 Crafton Avenue, Dayton, O.

1905. KNAPP, A. C. Manager Railway Department, Parrott Varnish Company, 102 Fulton Street, New York, N. Y.

1904. KNIGHT, FRANK B. Engineer, Lidgerwood Manufacturing Company, 96 Liberty Street, New York, N. Y.

1903. *KNIGHTON, J. A. Engineer in Charge of Construction, Blackwells Island Bridge, 56 Sutton Place, New York, N. Y.

1904. KNOWLES, MORRIS. Chief Engineer, Bureau of Filtration, Pittsburg, Pa.

1903. KOHR, D. A. Chemist, Lowe Brothers, Dayton, O.

1906. KRANZ, W. G. Superintendent, Steel Casting Works, Sharon, Pa.

1896. *KREUZPOINTNER, PAUL. Pennsylvania Railroad, Altoona, Pa.

1904. KRUPP COMPANY, FRIED. Emil Ehrensberger, Director, Essen, Germany.

1904. KUMMER, FREDERIC A. General Manager, United States Wood Preserving Company, 29 Broadway, New York, N. Y.

1903. LA CHICOTTE, H. A. Engineer in Charge, Manhattan Bridge (No. 3) and Blackwell's Island Bridge (No. 4), Park Row Building, New York, N. Y.

1905. *LACKAWANNA STEEL COMPANY. Franklin E. Abbott, Inspecting Engineer, Buffalo, N. Y.

1906. LANE, ALFRED M. General Superintendent, Mauran, Russell and Garden, 1620 Chemical Building, St. Louis, Mo.

1906. LANE, H. C. Chief Draftsman, Maryland Steel Company, Sparrows Point, Md.

1903. *LANE, HENRY M. 1137 Scofield Building, Cleveland, O.

1899. *LANZA, GAETANO. Professor Theoretical and Applied Mechanics, in charge Mechanical Engineering Department, Massachusetts Institute of Technology, Boston, Mass.

1904. *LARNED, E. S. Manager, United Building Materials Company, 101 Milk Street, Boston, Mass.

1903. LARSSON, C. G. E. Assistant Chief Engineer, American Bridge Company, 42 Broadway, New York, N. Y.

ELECTED.

1907. LAWSON, THOMAS R. Associate Professor of Rational and Technical Mechanics, Rensselaer Polytechic Institute, 99 Twelfth Street, Troy, N. Y.

1903. LAYMAN, W. A. General Manager, Wagner Electrical Manufacturing Company, 2017 Locust Street, St. Louis, Mo.

1906. LEIDEL, HENRY. Factory Superintendent, Banzai Manufacturing Company, 122 Green Street, Greenpoint, Brooklyn, N. Y.

1904. *LEMEN, W. W. Engineer of Tests, Norfolk and Western Railway, Roanoke, Va.

1906. LESCHEN, HARRY J. Engineer, Tramway Department, A. Leschen and Sons Rope Company, 920 North First Street, St. Louis, Mo.

1898. *†LESLEY, R. W. (*Vice-President*). President, American Cement Company, Pennsylvania Building, Philadelphia, Pa.

1906. LEWIS, FRANK D. District Representative, Robert W. Hunt and Company, West Fourth Avenue, Phœnixville, Pa.

1903. LEWIS, FREDERICK H. Consulting Engineer, Leeds, Jefferson County, Ala.

1906. LEWIS, GEORGE T. Secretary and Treasurer, Monongahela Iron and Steel Company, Post Office Box 215, Pittsburg, Pa.

1905. LEWIS, JOHN F. Chief Inspector, Duquesne Steel Works, Carnegie Steel Company, Duquesne, Pa.

1904. *LIDGERWOOD, JOHN H., JR. Engineer, Lidgerwood Manufacturing Company, 96 Liberty Street, New York, N. Y.

1905. *LIMA LOCOMOTIVE AND MACHINE COMPANY, THE. W. H. Agerter, Secretary and Treasurer, Lima, O.

1896. LINDENTHAL, GUSTAV. Consulting Engineer, 45 Cedar Street, New York, N. Y.

1906. LINTON, H. H. Salesman, Fuller Brothers and Company, 139 Greenwich Street, New York, N. Y.

1903. *LITTLE, A. D. Chemical Expert and Engineer, 93 Broad Street, Boston Mass.

1905. LLOYD, JOHN. Banker and Coal Operator, Altoona, Pa.

1903. LOBDELL, W. W. President, Lobdell Car-Wheel Company, Wilmington, Del.

1902. LOBER, J. B. Vice-President, Vulcanite Portland Cement Company, Land Title Building, Philadelphia, Pa.

1904. LOBER, W. H. Inspector General, Barber Asphalt Paving Company, Rialto Building, San Francisco, Cal.

ELECTED.

1905. *LOHMANN, H. W. Manager, James Stewart and Company, Engineers and Contractors, 302 Lincoln Trust Building, St. Louis, Mo.

1905. LONG, E. MCLEAN. Civil Engineer, Inspector of Steel, 220 Broadway, New York, N. Y.

1904. *LONG, R. A. President and General Manager, The Long-Bell Lumber Company, Keith and Perry Building, Kansas City, Mo.

1904. LONG, WILLIAM. Engineer of Tests, Bureau of Engraving and Printing, 2133 K Street, N., Washington, D. C.

1906. LOOS, EDWARD A. Chemist, 27 Elizabeth Street, Auburn, N. Y.

1907. LORD, RICHARD C. Engineer of Tests, Louisville and Nashville Railroad Company, South Louisville, Ky.

1903. LORDLY, HENRY ROBERTSON. Engineer in Charge, Lachine Canal, Royal Insurance Building, Montreal, Canada.

1904. LOUDENBECK, H. C. Chemist and Metallurgist, Westinghouse Air Brake Company, Wilmerding, Pa.

1903. LOUDON, ARCH. M. Foundryman, Elmira, N. Y.

1902. LOVELL, EARL B. Adjunct Professor of Civil Engineering, Columbia University, 235 West One Hundred and Second Street, New York, N. Y.

1906. LOW, WILSON H. Head Chemist, The Cudahy Packing Company, South Omaha, Neb.

1899. LOWE BROTHERS. Paint and Color Makers; Houston Lowe, Vice-President, Dayton, O.

1900. LOWETH, CHARLES F. Engineer and Superintendent of Bridges and Buildings, Chicago, Milwaukee and St. Paul Railway, 1232 Railway Exchange, Chicago, Ill.

1905. LUCAS AND COMPANY. John W. Irving Lewis, Consulting and Contracting Representative, 322–330 Race Street, Philadelphia.

1904. LUDLOW, S. H. Chemist, Empire Portland Cement Company, Warner, N. Y.

1905. LUKENS, ALAN N. Mechanical Engineer, Railway Steel Spring Company, 71 Broadway, New York, N. Y.

1902. *†LUKENS IRON AND STEEL COMPANY. Charles L. Huston, Vice-President, Coatesville, Pa.

1906. LUM, D. W. Chief Engineer, Maintenance of Way, Southern Railway Company, Washington, D. C.

1898. *LUNDTEIGEN, ANDREAS. Chemist, Union City, Mich.

ELECTED.

1906. LYNCH, THOMAS. President, H. C. Frick Coke Company, Carnegie Building, Pittsburg, Pa.

1902. LYNCH, T. D. Engineer of Material Tests, Westinghouse Electric and Manufacturing Company, East Pittsburg, Pa.

1902. MACPHERRAN, R S. Chemist, Allis-Chalmers Company, Milwaukee, Wis.

1905. MCCASKEY, H. D. Chief of the Mining Bureau, Department of Interior, Box 449, Manila, P. I.

1896. MCCAULEY, H. K. Secretary and Treasurer, Altoona Iron Company, Altoona, Pa.

1906. MCCORMACK, HARRY M. Associate Professor of Metallurgy, Armour Institute, Chicago, Ill.

1905. MCCREA, ARCHIBALD M. President, Union Spring and Manufacturing Company, Farmers' Bank Building, Pittsburg, Pa.

1903. *MCCREADY, ERNEST B. General Manager Lehigh Valley Testing Laboratory, Fourth and Linden Streets, Allentown, Pa.

1906. MCFARLAND, J. A. Chemist, Missouri Pacific Railway, St. Louis, Mo.

1905. MCGRADY, J. W. Chief Inspector, Homestead Steel Works, Carnegie Steel Company, Munhall, Pa.

1906. MCILHINEY, PARKER C. Consulting Chemist, 145 East Twenty-third Street, New York, N. Y.

1896. *MCKENNA, CHARLES F. Chemist, 221 Pearl Street, New York, N. Y.

1905. MCKIBBEN, FRANK P. Associate Professor of Civil Engineering, Massachusetts Institute of Technology, Boston, Mass.

1904. MCLEAN, E. Foreman, Wheel Foundry, Pennsylvania Railroad, Altoona, Pa.

1902. *†MCLEOD, JOHN (*Member of Executive Committee*). 1108 Pennsylvania Building, Philadelphia, Pa.

1904. *MCNAUGHER, D. W. Civil Engineer, Monongahela Bank Building, Pittsburg, Pa.

1903. MCQUEEN, J. W. Second Vice-President, Sloss-Sheffield Iron and Steel Company, Birmingham, Ala.

1904. *MACK, J. LATHROP. Chemist, Nazareth Cement Company, Nazareth, Pa.

ELECTED.

1895. *MACLAY, WILLIAM W. President, Glens Falls Portland Cement Company, Glens Falls, N. Y.

1906. MACLEAN, ALEX. J. Professor of Naval Architecture, Webb Academy, Fordham Heights, New York, N. Y.

1904. MAHON, R. W. Chemist, New York Central and Hudson River Railroad, West Albany, N. Y.

1902. MAJOR, CHARLES. President, A. and P. Roberts Company; Manager, Pencoyd Iron Works, Pencoyd, Pa.

1898. *MARBURG, EDGAR (*Secretary-Treasurer*). Professor of Civil Engineering, University of Pennsylvania, Philadelphia, Pa.

1906. MARIS, JOHN M. Principal, School of Structural Engineering, International Correspondence Schools, Scranton, Pa.

1905. *MARQUETTE CEMENT MANUFACTURING COMPANY. T. G. Dickinson, General Manager, La Salle, Ill.

1906. MARSHALL, S. M. Assistant Chief Engineer, Cambria Steel Company, Johnstown, Pa.

1906. MARSHALL, WILLIAM. President, The Anglo-American Varnish Company, 53 Johnson Street, Newark, N. J.

1905. MARSTEN, A. Dean of Division of Engineering, Iowa State College, Ames, Iowa.

1903. MARTIN, HENRY G. Metallurgist, Lukens Iron and Steel Company, P. O. Box 478, Coatesville, Pa.

1902. MARTIN, SIMON S. Superintendent, Maryland Steel Company, Sparrows Point, Md.

1903. MASTERS, J. B. Inspecting Engineer, Pittsburg Representative of Hildreth and Company, 506 North St. Clair Street, Pittsburg, Pa.

1906. MASURY AND SON, JOHN W. 44 Jay Street, Brooklyn, N. Y.

1902. MATCHAM, CHARLES A. Manager, Lehigh Portland Cement Company, Allentown, Pa.

1903. MATHEWS, JOHN A. Assistant Engineer, Sanderson Works, Crucible Steel Company of America, Syracuse, N. Y.

1904. *MAURER, E. R. Professor of Mechanics, University of Wisconsin, Madison, Wis.

1904. *MEAD, CHARLES ADRIANCE. Principal Assistant to Boller and Hodge, Engineers, New York, N. Y., 165 Wildwood Avenue, Upper Montclair, N. J.

1899. MEADE RICHARD K. Chemist, Dexter Portland Cement Company, Nazareth, Pa.

1905. MEANS, E. C. General Manager, The Low Moor Iron Company of Virginia, Low Moor, Va.

ELECTED.

1902. MEIER, E. D. President and Chief Engineer, Herne Safety Boiler Company, 11 Broadway, New York, N. Y.

1895. *MERRIMAN, MANSFIELD (*Past-President*). Professor of Civil Engineering, Lehigh University, South Bethlehem. Pa. Consulting Engineer, 45 Broadway, New York, N. Y.

1907. *METALLURGICAL LABORATORY, THE. C. B. Murray, President, 611 Bailey-Farrell Building, Pittsburg, Pa.

1903. METCALF, WILLIAM. Braeburn Steel Company, Braeburn, Pa.

1906. MICHAEL, LOUIS G. Chemist, Iowa Agricultural Experiment Station, Ames, Iowa.

1904. MILLAR W. G. A. Purchasing Agent, American Bridge Company, 30 Orchard Avenue, Bellevue, Pa.

1905. MILLER, H. C. Specialist in Steel Concrete Construction, 1 Madison Avenue, New York, N. Y.

1903. MILLER, JOHN S., JR. Assistant Chemist, Supervising Architect's Office, Treasury Department, Washington, D. C.

1903. MILLER, RUDOLPH P. Consulting Engineer, 527 Fifth Avenue, New York, N. Y.

1900. *MILLS, CHARLES M. Principal Assistant Engineer, Subway and Elevated Railroad Construction, Philadelphia Rapid Transit Company, Philadelphia, Pa.

1903. MITCHELL, ARTHUR M. Secretary, The Eureka Chemical Company, 5 Howard Street, Newark, N. J.

1904. MITCHELL, A. S. Analytical Chemist, 220 Greenbush Street, Milwaukee, Wis.

1903. †MITCHELL, JOSEPH. With John Williams Bronze and Iron Works, 556 West Twenty-seventh Street, New York City, N. Y.

1904. MIX, CHARLES DORF. Steel Merchant, 102 Purchase Street, Boston, Mass.

1905. MOECHEL, J. ROBT. Kansas City Chemic-Technic Laboratories, Eighth and Locust Streets, Kansas City, Mo.

1903. *MOISSEFF, LEON S. Assistant Engineer to Commissioner of Bridges, 13 Park Row, New York, N. Y.

1896. *MOLDENKE, RICHARD. Metallurgist, Consulting Engineer, Watchung, N. J.

1906. MONAGHAN, FRANK P. Chemist, Alpena Portland Cement Company, Alpena, Mich.

1906. MONTANA COLLEGE OF AGRICULTURE AND MECHANIC ARTS, Bozeman, Mont.

ELECTED.

1903. MOORE, HERBERT F. Assistant Professor of Mechanics, University of Wisconsin, 919 University Avenue, Madison, Wisconsin.

1906. MOORE, JOHN N. Representative, The Patterson-Sargent Company, 42 Hudson Street, New York, N. Y.

1905. MOORE, LEE C. Consulting Mechanical Engineer, 908 House Building, Pittsburg, Pa.

1902. MOORE, WILLIAM HARLEY. Engineer of Bridges, New York, New Haven and Hartford Railroad, New Haven, Conn.

1905. MORGAN CONSTRUCTION COMPANY. Victor E. Edwards, Mechanical Engineer, Worcester, Mass.

1905. *MORRISON, HUGH S. Mechanical Engineer, Mutual Assurance Society Building, Richmond, Va.

1905. MORROW, JAY J. Captain, Corps of Engineers, United States Army, Assistant to Engineers Commissioner, District of Columbia, District Building, Washington, D. C.

1905. MORSE, EDWIN KIRTLAND. Civil Engineer, Pittsburg, Pa.

1904. MOSELEY, ALEX. W. Professor of Applied Mechanics, Lewis Institute, Chicago, Ill.

1906. MOULTON, MACE. Consulting Engineer, 150 Nassau Street, New York, N. Y.

1904. †MUDGE, H. U. Second Vice-President, Chicago, Rock Island and Pacific Railway Company, La Salle Street Station, Chicago, Ill.

1899. *MUESER, WILLIAM. Civil Engineer; Member, Concrete Steel Engineering Company, 13-21 Park Row Building, New York, N. Y.

1903. MUNROE, CHARLES EDWARD. Head Professor of Chemistry, George Washington University, Washington, D. C.

1904. MUNSELL, A. W. Inspector of Materials, Detroit River Tunnel Company, Detroit, Mich.

1899. MUTUAL BOILER INSURANCE COMPANY. 31 Milk Street, Boston, Mass.

1905. *MYERS, JR., E. T. D. Civil Engineer, Mutual Assurance Society Building, Richmond, Va.

1904. NAEGELEY, JOHN C. Engineer and Architect, 102 Richmond Avenue, Buffalo, N. Y.

1905. NATIONAL FIRE PROOFING COMPANY. E. V. Johnson, Vice-President and Western Manager, 806 Hartford Building, Chicago, Ill.

ELECTED.

1900. NATIONAL TUBE COMPANY. Frank N. Speller, Metallurgical Engineer, Frick Building, Pittsburg, Pa.

1902. *NEFF, F. H. Professor of Civil Engineering, Case School of Applied Science, Cleveland, O.

1904. NEILSON, GEORGE HARRISON. General Manager, Braeburn Steel Company, Braeburn, Pa.

1904. *NELSON, E. D. Engineer of Tests, Pennsylvania Railroad Company, Altoona, Pa.

1906. NETTLETON, W. A. General Superintendent, Motive Power, Frisco System, 1133 Frisco Building, St. Louis, Mo.

1902. NEW YORK AIR BRAKE COMPANY, THE. R. C. Augur, Mechanical Engineer, Watertown, N. Y.

1904. NEW YORK FIRE INSURANCE EXCHANGE. Henry E. Hess, Manager, 32 Nassau Street, New York, N. Y.

1898. *NEWBERRY, SPENCER B. Manager, Sandusky Portland Cement Company, Sandusky, O.

1905. NEWELL, F. H. Chief Engineer, United States Reclamation Service, 1330 F Street, Washington, D. C.

1906. *NICHOLSON, EDWARD E. Assistant Professor of Chemistry, University of Minnesota, Minneapolis, Minn.

1906. *NIINA, YEIICHI. Cement Chemist, Syracuse, Ind.

1902. NORRIS, GEORGE L. Chemist, Standard Steel Works, Burnham, Pa.

1903. NORTON, C. L. Assistant Professor of Heat Measurement, Massachusetts Institute of Technology, Boston, Mass.

1905. NORTH, A. T. Chief Engineer, Western Department, National Fire Proofing Company, 806 Hartford Building, Chicago, Ill.

1906. *NOYES, WILLIAM A. Chemist, Bureau of Standards, Washington, D. C.

1906. O'CONNER, B. F. Secretary and Treasurer, The Seaboard Paint Company, 3 Washington Avenue, Brooklyn, N. Y.

1898. OLSEN, TINIUS. Tinius Olsen and Company, Testing Machines, 500 North Twelfth Street, Philadelphia, Pa.

1902. ONDERDONK, J. R. Engineer of Tests, Baltimore and Ohio Railroad, Mt. Clare, Baltimore, Md.

1903. †ORFORD COPPER COMPANY. 43 Exchange Place, New York, N. Y.

1902. ORTON, EDWARD, JR. Dean, College of Engineering, Ohio State University, and State Geologist of Ohio, Columbus, O.

ELECTED.

1898. OSBORN ENGINEERING COMPANY, THE. Frank C. Osborn, Cleveland, O.

1903. *OSTROM, JOHN N. Bridge Engineer, 1518 Farmers' Bank Building, Pittsburg, Pa.

1904. *OTIS, SPENCER. Mechanical Engineer, 1707 Railway Exchange Building, Chicago, Ill.

1902. OUTERBRIDGE, ALEX. E., JR. Chemist and Metallurgist, 1600 Hamilton Street, Philadelphia, Pa.

1904. *OWEN, JAMES. Civil Engineer, 196 Market Street, Newark, N. J.

1903. PAGE, LOGAN WALLER. Chief of Road Material Laboratory, United States Department of Agriculture, Washington, D. C.

1906. *PARKS, W. M. Commander, United States Navy, Bureau of Steam Engineering, Washington, D. C.

1906. PASCHKE, HERBERT. Waterproofing Specialist, 41 Park Row, New York, N. Y.

1906. PATTON, LUDINGTON. Secretary-Treasurer, Patton Paint Company, Milwaukee, Wis.

1906. PAYNE, HENRY. Professor of Engineering, South African College, Capetown, South Africa.

1904. PEARSON, HENRY. Vice-President and General Manager, Wason Manufacturing Company, Brightwood, Mass.

1896. PEASE, F. N. Assistant Chemist, Pennsylvania Railroad, 345 East Thirty-third Street, New York, N. Y.

1903. PECKITT, LEONARD. President, Empire Steel and Iron Company, Catasauqua, Pa.

1904. PEEBLES, JOHN. Factory Superintendent, J. I. Case Threshing Machine Company, 712 Lake Avenue, Racine Wis.

1902. †PENNSYLVANIA STEEL COMPANY, THE. H. H. Campbell, Superintendent and General Manager, Steelton, Pa.

1906. PEPPEL, S. V. Chemical Engineer, 1528 North High Street, Columbus, Ohio.

1904. PERLEY, GEORGE E. Cement Expert, Department of Public Works, Ottawa, Canada.

1905. PETERS, J. M. Manager, White Lead Department, W. J. Mathewson and Company, Limited, 200 Water Street, New York, N. Y.

1905. *PEW, J. HOWARD. Assistant Manager, Refinery, Sun Company, Marcus Hook, Pa.

ELECTED.

1903. PHILLIPS, WILLIAM BATTLE. Birmingham Testing Laboratory, Birmingham, Ala.

1905. PHLEGAR, A. A., JR. Chemist, Norfolk and Western Railway, Roanoke, Va.

1906. PIERCE, JR., N. W. Purchasing Agent, Raritan Copper Works, Perth Amboy, N. J.

1903 *PINCHOT, GIFFORD. Forester, United States Department of Agriculture, Washington, D. C.

1904. *PITTSBURG FORGE AND IRON COMPANY. F. E. Richardson, Secretary, Pittsburg, Pa.

1905. *PITTSBURG TESTING LABORATORY, LIMITED. John M. Bailey, Secretary, 325 Water Street, Pittsburg, Pa.

1905. PLATT, J. G. Engineer of Tests, Erie Railroad Company, Meadville, Pa.

1902. *†POLK, W. A. Sales Agent, The Patterson-Sargent Company, 42 Hudson Street, New York, N. Y.

1906. *POLSON, JOSEPH A. Post Office Box No. 166, Agricultural College, Mich.

1904. *POMEROY, LEWIS R. Special Representative, Railway Department, General Electric Company, 44 Broad Street, New York, N. Y.

1898. PORTER, JAMES MADISON. Professor of Civil Engineering, Lafayette College, Easton, Pa.

1903. POWELL, H. S. Sanitary Engineer, 327 Bond Street, Washington, D. C.

1904. POWELL, J. E. Chief Mechanical and Electrical Engineer, Office of Supervising Architect, Treasury Department, Washington, D. C.

1903. POWERS, W. A. Chief Chemist, Atchison, Topeka and Santa Fé Railroad, Topeka, Kan.

1904. PRENTISS, GEORGE N. Chemist, Chicago, Milwaukee and St. Paul Railway, 2910 Clybourn Street, Milwaukee, Wis.

1904. PRESTON, S. R. Superintendent, Virginia Portland Cement Company, Fordwick, Augusta County, Va.

1906. PRICE, CHARLES E. Cement Inspector, North River Division, Pennsylvania, New York, and Long Island Railroad, 564 West Thirty-third Street, New York, N. Y.

1903. PRICE, MORTON MOORE. Civil Engineer, Babcock and Wilcox Company, Bayonne, N. J.

1904. PRINCE, J. W. Vice-President, Freeborn Engineering and Construction Company, 708 Heist Building, Kansas City, Mo.

ELECTED.

1906. PRITHAM, HENRY C. Chief Chemist, Smith, Emery and Company, 1068 Broadway, Oakland, Cal.

1905. *PROVOST, ANDREW J., JR. Engineer to Commissioner of Public Works, 518 Fifth Avenue, New York N. Y.

1904. PURDON, C. D. Engineer, Maintenance of Way, Frisco System, Frisco Building, St. Louis, Mo.

1905. *QUICK, CHARLES DELAVAN. Superintendent, Alma Cement Company, Wellston, Ohio.

1904. QUIMBY, CHARLES H. Assistant Engineer, Yards and Buildings, American Bridge Company, 115 Rochelle Avenue, Wissahickon, Philadelphia, Pa.

1903. QUIMBY, H. H. Assistant Engineer of Bridges, Bureau of Surveys, 863 North Twenty-third Street, Philadelphia, Pa.

1898. RAILROAD GAZETTE. W. H. Boardman, Editor, 83 Fulton Street, New York, N. Y.

1902. RAILWAY AND ENGINEERING REVIEW. W. M. Camp, Editor, 1305 Manhattan Building, Chicago, Ill.

1904. RAMAGE, J. C. Superintendent of Tests, Southern Railway Company, Alexandria, Va.

1904. *RAMSAY, H. MARTYN. General Inspector, Pennsylvania Railroad Company, Altoona, Pa.

1896. *RANDOLPH, LINGAN S. Professor of Mechanical Engineering, Virginia Polytechnic Institute, Blacksburg, Va.

1905. READ, C. P. Assistant Engineer, Interborough Rapid Transit Company, 75 East Fifty-Fourth Street, New York, N. Y.

1902. READING IRON COMPANY. Reading, Pa.

1905. REBER, LOUIS E. Dean, School of Engineering, The Pennsylvania State College, State College, Pa.

1904. REEVE, C. S. Assistant Inspector of Asphalt and Cement, District Building, Washington, D. C.

1902. REID, DAVID. General Foreman, Foundry Department, Canadian Westinghouse Company, Limited, 253 Wentworth Street, Hamilton, Canada.

1907. REIMER, ARTHUR A. Engineer and Superintendent, East Orange Water Department, City Hall, East Orange, N. J.

1906. REW, W. E. Inspector of Asphalts and Cements, Post Office Box 451, Norfolk, Va.

1906. REYNDERS, J. V. W. Vice-President, Pennsylvania Steel Company, Steelton, Pa.

ELECTED.

1905. REYNOLDS, J. C. Assistant Engineer Brooklyn Rapid Transit Railroad Commission, 6 West One Hundred and Twenty-ninth Street, New York, N. Y.

1898. RICE, FRANCIS S. Engineer of Bridges, St. Louis and San Francisco Railroad Company, 943 Frisco Building, St. Louis, Mo.

1900. RICHARDS, JOSEPH T. Chief Engineer, Maintenance of Way, Pennsylvania Railroad, Broad Street Station, Philadelphia, Pa.

1902. *RICHARDS, JOSEPH W. Professor of Metallurgy, Lehigh University, South Bethlehem, Pa.

1902. RICHARDS, ROBERT H. Professor of Mining Engineering and Metallurgy, Massachusetts Institute of Technology, Boston, Mass.

1904. *RICHARDS, W. D. Houghton and Richards, 150 Oliver Street, Boston, Mass.

1896. *RICHARDSON, CLIFFORD. Asphalt Expert, New York Testing Laboratory, Long Island City, N. Y.

1903. RICHARDSON, WILLARD D. Ceramic Engineer, Columbus, O.

1900. RICHTER, A. W. Professor of Experimental Engineering, University of Wisconsin, 929 University Avenue, Madison, Wis.

1906. *RIDDLE, WALTER. Vice-President, Sterling Varnish Company, Pittsburg, Pa.

1902. RIEGNER, W. B. Engineer of Bridges, Philadelphia and Reading Railway, Reading Terminal, Philadelphia.

1898. *RIEHLE, FREDERICK A. Riehlé Brothers Testing Machine Company, 1424 North Ninth Street, Philadelphia, Pa.

1906. RILEY, GEORGE N. National Tube Company, Frick Building, Pittsburg, Pa.

1904. *ROBERTS, ALFRED E. Analytical and Consulting Chemist and Metallurgist, Bull and Roberts, 100 Maiden Lane New York, N. Y.

1904. ROBERTSON, LESLIE S Secretary of the Engineering Standards Committee, 28 Victoria Street, London, England.

1904. ROBINSON, A. F. Bridge Engineer, Atchison, Topeka and Santa Fé Railway System, 1000 Railway Exchange Building, Chicago, Ill.

1905. *ROBINSON, HOLTON D. Engineer in Charge of Manhattan Bridge, 21 Park Row, New York, N. Y.

ELECTED

1904. ROCK PRODUCTS. Fred K. Irvine, Technical Editor, 431 West Main Street, Louisville, Ky.

1906. ROCKWELL, GEORGE W. Chief Chemist, Lehigh Portland Cement Company, 513 Chew Street, Allentown, Pa.

1906 RODGERS, S. M. Superintendent, North Works, American Steel and Wire Company, Worcester, Mass.

1900. *ROEBLING'S SONS COMPANY, JOHN A. H. J. Horne, Assistant Superintendent, Department of Wiredrawing, Trenton, N. J.

1904. ROEPPER, C. W. Metallurgical Engineer, Mount Airy Station, Philadelphia, Pa.

1905. *ROSENHEIM, A. F. Architect, H. W. Hellman Building, Los Angeles, Cal.

1905. *ROSSI, JAMES C. General Superintendent, National Fire Proofing Company, 71 Lewis Street, Perth Amboy, N. J.

1903. ROYAL, JOSEPH. Inspecting Engineer, P. O. Box 174, Rutledge, Pa.

1906. RUGGLES, WM. B. Mechanical Engineer, 39 Cortlandt Street, New York, N. Y.

1906. *RUSSELL, ERNEST JOHN. Architect, Chemical Building, St. Louis, Mo.

1904. RUTHENBURG, MARCUS. Electro-Metallurgical Engineer, Lockport, N. Y.

1898. SABIN, A. H. Chemist, 432 Sanford Avenue, Flushing, N. Y.

1902. SABIN, L. C. Secretary, American Section, International Waterways Commission, St. Mary's Falls Canal, Sault Ste. Marie, Mich.

1902. SAGUE, J. E. Vice-President, American Locomotive Company, 111 Broadway, New York, N. Y.

1904. SALMON, FREDERICK W. Civil and Mechanical Engineer, 127 South Central Avenue, Burlington, Iowa.

1904. SAUNDERS, GEORGE C. Manager Eastern District, The Osborn Engineering Company, 1022 Land Title Building, Philadelphia, Pa.

1902. SAUNDERS, WALTER M. Analytical and Consulting Chemist, 184 Whittier Avenue, Providence, R. I.

1896. *SAUVEUR, ALBERT. Metallurgical Engineer; Professor of Metallurgy, Harvard University; Rotch Building, Harvard University, Cambridge, Mass.

1903. SCARBOROUGH, F. W. Mining Engineer, Macdonald, W. Va.

ELECTED.

1904. SCHADE, G. C. 297 Main Street, Arsenal Station, Pittsburg, Pa.

1904. SCHENK, PIERCE D. Vice President and Assistant General Manager, The Dayton Malleable Iron Company, Dayton, O.

1904. *SCHMITT, F. E. Associate Editor, *The Engineering News*, 220 Broadway, New York, N. Y.

1905. SCHNEIDER, C. C. Consulting Engineer, Pennsylvania Building, Philadelphia, Pa.

1900. SCHNEIDER, HERMAN. Professor of Civil Engineering, University of Cincinnati, Cincinnati, O.

1906. SCHNELL, HARRY J. Manager, *The Painters Magazine*, 100 William Street, New York, N. Y.

1905. *SCHNIEWIND, F. Consulting Chemical Engineer; Vice-President, The United Coke and Gas Company, 17 Battery Place, New York, N. Y.

1906. SCHOOL OF ENGINEERING, University of Kansas. F. O. Martin, Dean, Lawrence, Kan.

1903. SCHROEDER, C. M. Chemist, 221 Pearl Street, New York N. Y.

1902. SCHUERMAN, W. H. Dean of Engineering Department and Professor of Civil Engineering, Vanderbilt University, Nashville, Tenn.

1905. SCHWARTZ, ARCHIE W. Inspector, Bureau of Buildings, Borough of Manhattan, 65 West Eleventh Street, New York, N. Y.

1904. *SCOTT, WILLIAM F. Structural Engineer, Aberdeen Chambers, Toronto, Can.

1902. *SCOTT, W. G. Chemist, J. I. Case Threshing Machine Company, 1109 Park Avenue, Racine, Wis.

1905. SCRIBNER, C. E. Chief Engineer, Western Electric Company, 463 West Street, New York, N. Y.

1898. SEAMAN, HARRY J. Superintendent, Atlas Cement Company, Catasauqua, Pa.

1902. SEAMAN, HENRY B. Civil Engineer, 40 Wall Street, New York, N. Y.

1906. SEARS, W. T. Engineering Bureau, Niles-Bement-Pond Company, Twenty-first and Callowhill Streets, Philadelphia, Pa.

1904. *SELLERS AND COMPANY, INCORPORATED, WILLIAM. Coleman Sellers, Jr., President, 1600 Hamilton Street, Philadelphia, Pa.

ELECTED.

1906. *SEMET-SOLVAY COMPANY. O. S. Doolittle, Sales Agent, 17 Battery Place, New York, N. Y.

1902. *SHANKLAND, E. C. AND R. M. Civil Engineers, 1106 Rookery, Chicago, Ill.

1907. SHAW, SAMUEL J., JR. Borough Engineer, Ridgefield Park, N. J.

1903. SHEAFF, J. C. Manager, Patterson-Sargent Company, 42 Hudson Street, New York, N. Y.

1902. *SHELBY STEEL TUBE COMPANY. J. H. Nicholson, Third Vice-President, Frick Building, Pittsburg, Pa.

1904. SHERMAN, HERBERT L. Analytical Chemist, 220 Devonshire Street, Boston, Mass.

1906. SHERRERD, JOHN M. General Sales Agent, Taylor Iron and Steel Company, High Bridge, N. J.

1903. SHERRERD, MORRIS R. Engineer and Superintendent, Department of Water, City of Newark, 128 Halsey Street, Newark, N. J.

1902. SHERWIN-WILLIAMS COMPANY, THE. Paint and Varnish Makers, E. C. Holton, Chemist in Chief, 100 Canal Street, Cleveland, O.

1899. *SHIMER, PORTER W. Chemist and Metallurgist, Easton, Pa.

1906. SHULTS, CHARLES. Salesman, Worth Brothers Company, 111 Broadway, New York, N. Y.

1902. SHUMAN, JESSE J. Chief Inspector, Testing Department, Jones and Laughlin Steel Company, Pittsburg, Pa.

1904. SIMMONS, WILLIAM H. Chief Chemist, Detroit Portland Cement Company, Fenton, Mich.

1904. SIMPSON BROTHERS CORPORATION. 166 Devonshire Street, Boston, Mass.

1906. SINCLAIR, D. G. Representative, Illinois Steel Company, 6304 Marchant Street, Pittsburg, Pa.

1903. *SKINNER, C. E. Electrical Engineer, Westinghouse Electric and Manufacturing Company, East Pittsburg, Pa.

1904. *SKINNER, ORVILLE CAMPBELL. Superintendent, Open-Hearth Department, Standard Steel Works, P. O. Box 165, Burnham, Pa.

1906. SMART, L. A. Analyst for City Works Department, Old Waterworks, Winnipeg, Man.

1907. SMITH, CHARLES E. Field Assistant, U. S. Geological Survey, Washington, D. C.

1906. SMITH, EMERY AND COMPANY. Chemists and Chemical Engineers, 1104 Broadway, Oakland, Cal.

ELECTED.

1906. *SMITH, E. B. In Charge Mechanical Laboratories, Drexel Institute, Thirty-second and Chestnut Streets, Philadelphia, Pa.

1902. *SMITH, H. E. Chemist, The Lake Shore and Michigan Southern Railway Company, Collinwood, O.

1905. SMITH, JAMES CRUICKSHANK. Chemical Engineer and Color Trade Expert, 5 The Elms, London Road, Wembley, Middlesex, England.

1904. SNODGRASS, A. E. Portland Cement Department, Louisville Cement Company, Sellersburg, Ind.

1902. *SNOW, J. P. Bridge Engineer, Boston and Maine Railroad, Boston, Mass. *For Mail*, 58 Chandler Street, West Somerville, Mass.

1905. *SNOW, WALTER B. Manager, Advance Department, B. F. Sturtevant Company, Hyde Park, Mass.

1904. *SOLVAY PROCESS COMPANY, THE. George B. Hartley, Chief Inspector, Syracuse, N. Y.

1904. SOMERVILLE, C. W. Computer in charge of Tests, Building Department, Washington, D. C.

1903. *SOUTHER, HENRY. Consulting Metallurgical Engineer, State Chemist, 440 Capitol Avenue, Hartford, Conn.

1904. *SPACKMAN, HENRY S., ENGINEERING COMPANY. 42 North Sixteenth Street, Philadelphia, Pa.

1905. SPALDING, F. P. Professor of Civil Engineering, University of Missouri, Columbia, Mo.

1902. SPANGLER, H. W. Professor of Mechanical Engineering, University of Pennsylvania, Philadelphia, Pa.

1905. SPARE, C. R. Chemist, Wm. Cramp and Sons Ship and Engine Building Company, Beach and Ball Streets, Philadelphia, Pa.

1906. SPARHAWK, GEORGE F. Engineer, American Bridge Company, Ambridge, Pa.

1901. SPERRY, W. L. Superintendent and Manager, The Cumberland Hydraulic Cement and Manufacturing Company, Post Office Box 264, Cumberland, Md.

1906. SPRAGUE, L. G. Chemist, Virginia Portland Cement Company, Fordwick, Va.

1902. *STANDARD STEEL WORKS. A. A. Stevenson, Assistant Superintendent, Burnham, Pa.

1905. *STANGER, R. H. HARRY. Consulting Engineer, Testing Works and Chemical Laboratories, 2 Broadway, Westminster, London, S. W., England.

ELECTED.

1903. STAPLETON, F. M. Inspector, Chicago and Northwestern Railway, 504 Smithfield Street, Pittsburg, Pa.

1904. *STATTELMANN, G. R. 37 West Washington Street, Dayton, Ohio.

1906. STEFFENS, WM. FREDERICK. Engineer of Bridges and Buildings, South and Western Railway Company, Johnson City, Tenn.

1899. STEINMAN, A. J. Chairman, Pennsylvania Iron Company, Limited, Lancaster, Pa.

1906. STEPHENSON, J. T. Inspector, Southern Railway Company, Post Office Box 66, Phœnixville, Pa,

1896. *STEVENSON, A. A. Assistant Superintendent, Standard Steel Works, Burnham, Mifflin County, Pa.

1903. STEWART, CLINTON R. Assistant Superintendent, Open Hearth Department, Cambria Steel Company, Johnstown, Pa.

1904. STEWART, P. M. Consulting Engineer, The Nevada, Broadway and Seventieth Street, New York, N. Y.

1906. STILLMAN, HAVARD. Engineer of Tests, Southern Pacific Company, 2434 Piedmont Avenue, Berkeley, Cal.

1899. *STILLMAN, THOMAS B. Professor of Chemistry, Stevens Institute of Technology, Hoboken, N. J.

1903. STOREY, W. B., JR. Chief Engineer, Atchison, Topeka and Sante Fé Railroad Company, 1033 Railway Exchange Building, Chicago, Ill.

1904. STORMER, EDWARD J. Chemist, Case Threshing Machinery Company, Racine, Wis.

1906. STORRS, L. S. Engineer of Tests, New York, New Haven and Hartford Railroad Company, Hew Naven, Conn.

1902. *STOUGHTON, BRADLEY. Adjunct Professor of Metallurgy and Consulting Metallurgist, Columbia University, New York, N. Y.

1906. STOUT, HOWARD A. Architect, Post Office Box 617, Atlantic City, N. J.

1903. STRATTON, E. PLATT. 66–70 Beaver Street, New York, N. Y.

1903. STREETER, LAFAYETTE P. Air Brake Inspector, Southern Pacific Company. *For Mail:* Post Office Box 1345, Los Angeles, Cal.

1896. *STROBEL, CHARLES L. Consulting Engineer, 1744 Monadnock Block, Chicago, Ill.

1904. *STUETZ, E. Vice-President and Treasurer, The Goldschmidt Thermit Company, 43 Exchange Place, New York, N. Y.

ELECTED.

1906. SUYDAM, RICHARD S. President, M. B. Suydam Paint Company, Pittsburg, Pa.

1896. *SWAIN, GEORGE F. Professor of Civil Engineering, Massachusetts Institute of Technology, Boston, Mass.

1903. SWANBERG, F. L. Secretary, The D. T. Williams Valve Company, 904–910 Broadway, Cincinnati, O.

1907. *SWENSON, P. W. Superintendent of Bridges and Buildings, Minneapolis, St. Paul and Sault Sainte Marie Railway Company, Shoreham Shops, Minneapolis, Minn.

1903. *SWENSSON, EMIL. Consulting Engineer, Frick Building, Pittsburg, Pa.

1904. SWING, S. WALTER. Assistant to Engineer of Tests, Lukens Iron and Steel Company, Coatesville, Pa.

1905. *TABER, GEORGE H. General Manager, Gulf Refining Company, Frick Building, Pittsburg, Pa.

1903. TAGGART HOWARD. Engineer of Tests, Lukens Iron and Steel Company, Post Office Box 632, Coatesville, Pa.

1898. *TALBOT, ARTHUR N. Professor of Municipal and Sanitary Engineering, University of Illinois, Urbana, Ill.

1902. *TALBOT, HENRY P. Professor of Inorganic and Analytical Chemistry, Massachusetts Institute of Technology, Boston, Mass.

1904. TASSIN, WIRT. Chemist; Assistant Curator, National Museum, Washington, D. C.

1904. TAUBENHEIM, ULRICH E. Manager, City Water Works, Archangel, Russia.

1906. TAYLOR, KNOX. General Manager, Taylor Iron and Steel Company, High Bridge, N. J.

1900. TAYLOR, WILLIAM PURVES. Engineer in Charge, Testing Laboratory, 318 City Hall, Philadelphia, Pa.

1896. *TECHNISCHER VEREIN, NEW YORK. Carl Kaelble, Secretary, Room 705, 290 Broadway, New York, N. Y.

1896. *TECHNISCHER VEREIN, PITTSBURG. Gustav A. Stielrin, Secretary, 166 Robinson Street, Pittsburg, Pa.

1896. TECHNISCHER VEREIN, WASHINGTON. Paul Bausch, Corresponding Secretary, 3418 Brown Street, N. W., Washington, D. C.

1902. THACHER, EDWIN. Consulting Engineer; Member, Concrete-Steel Engineering Company, Park Row Building, New York, N. Y.

ELECTED

1906. *THOMAS, A. R. Commonwealth Steel Company, St. Louis, Mo.

1900. *THOMAS, DAVID. Logan Iron and Steel Company, Burnham, Pa.

1906. THOMPSON, G. SAXTON. Assistant in Mechanics, Rennselaer Polytechnic Institute, 861 Second Avenue, Upper Troy, Troy, N. Y.

1903. *THOMPSON, GUSTAVE W. Chemist, National Lead Company, 129 York Street, Brooklyn, N. Y.

1905. *THOMPSON, HUGH L. Consulting Engineer, Waterbury, Conn.

1904. *THOMPSON, SANFORD E. Civil Engineer, Newton Highlands, Mass.

1904. THOMSON, FRANK K. Barrett and Thomson, Post Office Box No. 574, Raleigh, N. C.

1906. TIEMANN, HARRY D. Assistant Forest Inspector, U. S. Forest Service, Yale Forest School, New Haven, Conn.

1905. *TILDEN, C. J. Assistant Professor of Civil Engineering, University of Michigan, 320 Engineering Building, Ann Arbor, Mich.

1905. TOBELMANN, HENRY A. Chemist, United States Reclamation Service, Roosevelt, Ariz.

1903. *TOCH, MAXIMILIAN. Paint Manufacturer, 320 Fifth Avenue, New York, N. Y.

1903. TOMKINS, CALVIN. Manufacturer, 17 Battery Place, New York, N. Y.

1903. TOUCEDA, ENRIQUE. Chemist and Metallurgist, 51 State Street, Albany, N. Y.

1906. TRAUTWEIN, A. P. President, Carbondale Machine Company, Carbondale, Pa.

1906. TRETCH, WM. J. Superintendent, Riehlé Brothers Testing Machine Company, 1424 North Ninth Street, Philadelphia, Pa.

1905. *TRIST, N. B. Assistant to Vice-President, The Schoen Steel Wheel Company, Box 1212, Pittsburg, Pa.

1904. TROOIEN, O. N. Assistant in Mechanical Engineering, South Dakota Agricultural College, Brookings, S. Dak.

1906. *TURNER, HENRY C. President, Turner Construction Company, 11 Broadway, New York, N. Y.

1902. *TURNEAURE, F. E. Dean of the College of Mechanics and Engineering, University of Wisconsin, Madison, Wis.

1906. *TURNEY, OMAR A. City Engineer, Phoenix, Ari.

ELECTED.

1902. UMSTEAD, C. H. Superintendent of Construction, United States Public Buildings, 422 Washington Trust Building, Washington, Pa.

1906. VANDEVORT, F. F. Eastern Sales Agent, Wheeling Mold and Foundry Company, 374 Fifth Avenue, New York, N. Y.

1904. VAN CLEVE, A. H. Resident Engineer, The Niagara Falls Power Company, Niagara Falls, N. Y.

1903. VAN GUNDY, C. P. Chief Chemist, Baltimore and Ohio Railroad, Mont Clare, Baltimore, Md.

1902. *VAN ORNUM, J. L. Professor of Civil Engineering, Washington University, St. Louis, Mo.

1903. VANNIER, CHARLES H. Consulting Engineer, 76 Harvard Place, Buffalo, N. Y.

1896. VOGT, A. S. Mechanical Engineer, Pennsylvania Railroad, Altoona, Pa.

1904. VON AMMON, S. Consulting Engineer, Oswaldestre House, Norfolk Street, Strand, London, W. C., England.

1906. VON MARLE, C. M. Chemist, Pratt and Lambert, 79 Tonawanda Street, Buffalo, N. Y.

1903. VON SCHRENK, HERMANN. Pathologist, Bureau of Plant Industry, United States Department of Agriculture, Missouri Botanical Gardens, St. Louis, Mo.

1902. VOORHEES, S. S. Engineer of Tests, Treasury Department, Washington, D. C.

1903. *VREDENBURGH, WATSON, JR. Member, Hildreth and Company, Engineers, 50 Broadway, New York, N. Y.

1904. *WACHTER, CHARLES LUCAS. Assistant Engineer, Lidgerwood Manufacturing Company, 96 Liberty Street, New York, N. Y.

1896. WADDELL, J. A. L. Consulting Civil Engineer, Kansas City, Mo.

1904. WAGENHORST, JAMES H. Westinghouse Machine Company, Pittsburg, Pa.

1899. *WAGNER, SAMUEL TOBIAS. Assistant Engineer, Philadelphia and Reading Railway, Reading Terminal, Philadelphia, Pa.

1903. WAID, D. EVERETT. Architect, 156 Fifth Avenue, New York, N. Y.

1904. WALDO BROS. 102 Milk Street, Boston, Mass.

ELECTED.

1902. *WALKER, JOSEPH F. Chemist, The Protectus Company, Bridgeport, Pa.

1903. WALKER, R. F. Cement Tester in Charge, Rapid Transit Railway, New York, 412 Turner Street, Allentown, Pa.

1905. *WALKER, WILLIAM H. Professor of Industrial Chemistry, Massachusetts Institute of Technology, 24 Trinity Place, Boston, Mass.

1904. *WALLACE, E. C. Post Office Box 241, East Auburn, Cal.

1903. *WALSH, W. F. American Brake Shoe and Foundry Company, 408 Allen Avenue, Richmond, Va.

1903. *WALTER, LEE W. Cement Inspector, Erie Railroad, Ninth and Provost Streets, Jersey City, N. J.

1905. WARD, C. E. Oil Inspector, Pittsburg Coal Company, Banksville, Pa.

1904. WARDELL, H. R. General Sales Agent, Barber Asphalt Paving Company, Philadelphia, Pa.

1905. *WARMAN, F. C. United States Assistant Engineer, 1000 Twenty-second Street, Washington, D. C.

1903. WARNER, GEORGE C. Sullivan Machinery Company, Post Office Box 33, Claremont, N. H.

1905. WARREN BROTHERS COMPANY, 93 Federal Street, Boston, Mass.

1906. WASHINGTON UNIVERSITY. C. M. Woodward, Dean of School of Engineering and Architecture, St. Louis, Mo.

1904. WASON, LEONARD C. President, Aberthaw Construction Company, 8 Beacon Street, Boston, Mass.

1906. WEEKS, PAUL. Engineer of Tests, Baldwin Locomotive Works, Philadelphia, Pa.

1904. WEBB, Z. Chief Chemist, Eliza Furnace, Jones and Laughlin Steel Company, *For Mail:* 861 Lilac Street, Pittsburg, Pa.

1900. *WEBSTER, GEORGE S. Chief Engineer and Surveyor, Bureau of Surveys, 318 City Hall, Philadelphia, Pa.

1898. *WEBSTER, WILLIAM R. Civil Engineer, 411 Walnut Street, Philadelphia, Pa.

1906. WELD, HAROLD KENNETH. Assistant to Material Engineer, Engineering Department, Chicago Telephone Company, 127 College Street, Elgin, Ill.

1903. *WEMLINGER, J. R. President, Wemlinger Steel Piling Company, 150 Nassau Street, New York, N. Y.

ELECTED.

1904. WENTWORTH, CHARLES C. Principal Assistant Engineer, Norfolk and Western Railway, Roanoke, Va.

1905. WENTZ, DANIEL B. President, Stonega Coal and Coke Company, 1723 Land Title Building, Philadelphia, Pa.

1897. WEST, THOMAS D. Foundry Expert, Sharpsville, Pa.

1904. WESTINGHOUSE ELECTRIC AND MANUFACTURING COMPANY, L. A. Osborne, Vice-President, Post Office Box 911, Pittsburg, Pa.

1906. WETTACH, CHARLES D. Secretary, W. W. Lawrence and Company, West Carson Street, Pittsburg, Pa.

1906. WHARFF, WM. H. Architect, 2000 Delaware Street, Berkeley, Cal.

1906. WHEELER, EDWARD J. Consulting Chemist, 79 Chapel Street, Albany, N. Y.

1905. WHEELER, FRANK A. Inspecting Engineer, Harrison Building, Philadelphia, Pa.

1905. WHINERY, S. Consulting Engineer on Pavements, Borough of Manhattan, New York, 95 Liberty Street, New York, N. Y.

1906. WHITE, EVERETT HANSON. In charge Engineering Department, E. C. and B. Company Plant, No. 1, 91 Fremont Street, Bridgeport, Conn.

1906. WHITE, G. D. Manager, Patton Paint Company, Newark, N. J.

1900. *WHITEHEAD, J. W., JR. Preservative Coatings, 1 Madison Avenue, New York, N. Y.

1902. WHITNEY, WILLIS R. Research Laboratory, General Electric Company, Schenectady, N. Y.

1898. WICKHORST, MAX H. Engineer of Tests, Chicago, Burlington and Quincy Railway Company, Aurora, Ill.

1904. WILCOX, LEWIS G. Inspector of Steel, New York Rapid Transit Railroad Commission, 613 Empire Building, Pittsburg, Pa.

1906. WIELAND, CHARLES F. Consulting Engineer, 911 Mutual Saving Bank Building, San Francisco, Cal.

1902. WILHELM COMPANY, THE A. Paint Makers, Reading, Pa.

1898. WILLE, H. V. Assistant to Superintendent, Baldwin Locomotive Works, 500 North Broad Street, Philadelphia, Pa.

1905. WILLIAMSON, SYDNEY B. Consulting Engineer, Equitable Building, Baltimore, Md.

ELECTED.

1906. WILSON, EDWARD F. Chemist, Westmoreland Coal Company, Irwin, Pa.

1906. WINCHESTER REPEATING ARMS COMPANY. R. L. Penny, in Charge of Physical Laboratory, New Haven, Conn.

1900. *WING, CHARLES B. Professor of Structural Engineering, Stanford University, Cal.

1903. WITTMAN, N. B. Potts and Wittman, North American Building, Philadelphia, Pa.

1906. WOLF, OTTO C. Engineer and Architect, 1025 Arch Street, Philadelphia, Pa.

1903. *WOLFEL, PAUL L. Chief Engineer, American Bridge Company, 362 Green Lane, Roxborough, Philadelphia, Pa.

1902. *WOOD AND COMPANY, R. D., Founders. Walter Wood, 400 Chestnut Street. Philadelphia, Pa.

1903. WOOD, EDWARD R., JR. Manufacturer, 400 Chestnut Street, Philadelphia, Pa.

1903. WOOD, F. W. President, Maryland Steel Company, Sparrows Point, Md.

1900. *WOOD, WALTER. Cast-Iron Pipe Manufacturer, R. D. Wood and Company, 400 Chestnut Street, Philadelphia, Pa.

1906. WOODCOCK, W. H. Consulting Engineer, 910 Mutual Life Building, Buffalo, N. Y.

1903. WOODMAN, DURAND. Analytical and Technical Chemist, 80 Beaver Street, New York, N. Y.

1906. WOODS, R. W. Chief Chemist, Northern Pacific Railway Company, General Office Building, St. Paul, Minn.

1906. WOODWELL, JULIAN E. Inspector of Electric Light Plants, Treasury Department, Washington, D. C.

1900. *WOOLSON, IRA H. Adjunct Professor of Mechanical Engineering, Columbia University, New York, N. Y.

1904. *WORCESTER, JOSEPH R. J. R. Worcester and Company, 79 Milk Street, Boston, Mass.

1905. WORCESTER POLYTECHNIC INSTITUTE. William W. Bird, Director of the Department of Mechanical Engineering, Worcester, Mass.

1904. WORMELEY, P. L., JR. Engineer of Tests, Division of Tests, United States Department of Agriculture, Washington, D. C.

1903. WORTHINGTON, CHARLES. Consulting Engineer, 204 West Ninety-fourth Street, New York, N. Y.

ELECTED.

1906. WREAKS, HUGH. Secretary, Wire Inspection Bureau, 47 Cedar Street, New York, N. Y.

1906. WYMAN AND GORDON COMPANY, THE. George F. Fuller, General Superintendent and Secretary, Worcester, Mass.

1904. YAMAMOTO, YOSHIO. Mechanical Engineer, Tokyo, Japan.

1905. YOUNG, JOHN P. General Manager, Youngstown Car Manufacturing Company, Youngstown, O.

1903. ZEHNDER, C. H. President, Alleghany Ore and Iron Company, Pennsylvania Building, Philadelphia, Pa.

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Alabama	5	Massachusetts	54	Tennessee	2
Arizona	3	Michigan	9	Texas	1
California	18	Minnesota	4	Virginia	25
Colorado	6	Missouri	26	Washington	4
Connecticut	12	Montana	2	West Virginia	4
Delaware	4	Nebraska	3	Wisconsin	12
Dist. of Columbia	35	New Hampshire	1	Canada	17
Idaho	1	New Jersey	30	Cuba	1
Illinois	57	New York	210	England	7
Indiana	12	North Carolina	2	France	1
Iowa	4	Ohio	38	Germany	3
Kansas	4	Oregon	1	Philippine Is.	2
Kentucky	4	Pennsylvania	249	Porto Rico	1
Louisiana	1	Rhode Island	3	Russia	1
Maine	3	South Carolina	1	South Africa	1
Maryland	14	South Dakota	2		

Total membership 900

Total number holding membership also in the International Association for Testing Materials 247

DECEASED MEMBERS.

Name.	Date of Membership.	Date of Death.
J. W. Anderson	1896	May 18, 1905.
Edward Atkinson	1903	December 11, 1905
W. P. Black	1896	December 12, 1902.
Henry I. Budd	1903	January 14, 1905.
Thomas M. Drown	1899	November 16, 1904
Henry U. Frankel	1903	December 8, 1903.
Charles Jarecki	1896	January 26, 1901.
J. B. Johnson	1899	June 23, 1902.
W. C. Johnson	1900	December 15, 1906.
G. M. McCauley	1898	May 25, 1901.
George S. Morison	1896	July 1, 1903.
Henry Morton	1896	May 9, 1902.
Geo. Tatnall,	1906	September 13, 1906.
Robert H. Thurston	1896	October 25, 1903.
H. H. Wright	1904	June 22, 1905.
W. H. Wyman	1905	November 11, 1905.

PAST OFFICERS.

NOTE.—The Society, from its organization in 1898 till its incorporation under its present name in 1902, was designated the American Section of the International Association for Testing Materials.

The officers and members of the Executive Committee during this four-year period were as follows:

CHAIRMEN:

MANSFIELD MERRIMAN, 1898–1900.

HENRY M. HOWE, 1900–1902

VICE-CHAIRMEN:

HENRY M. HOWE 1898-1900.

CHARLES B. DUDLEY 1900–1902.

SECRETARIES:

RICHARD L. HUMPHREY, 1898–1900.

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TREASURERS:

PAUL KREUZPOINTNER, 1898–1900.

R. W. LESLEY, 1900–1902.

MEMBERS OF EXECUTIVE COMMITTEE:

GUS. C. HENNING, 1898–1900.

ALBERT LADD COLBY, 1900–1902.

STANDING ADVISORY COMMITTEES.

On Iron and Steel.

William R. Webster, *Chairman.*

H. H. Campbell, H. V. Wille.

On Cast Iron.

Richard Moldenke, *Chairman.*

Henry Souther, Thos. D. West.

On Cement and Concrete.

Clifford Richardson, *Chairman.*

Richard L. Humphrey, Spencer B. Newberry.

On Brick and Terra-cotta Products.

Edward Orton, Jr., *Chairman.*

H. O. Hofman, W. D. Richardson.

On Preservative Coatings.

G. W. Thompson, *Chairman.*

Robert Job, S. S. Voorhees.

On Tests and Testing Apparatus.

Gaetano Lanza, *Chairman.*

Mansfield Merriman, Tinius Olsen.

TECHNICAL COMMITTEES

OF THE

AMERICAN SOCIETY FOR TESTING MATERIALS.

COMMITTEE A, ON STANDARD SPECIFICATIONS FOR IRON AND STEEL.

WILLIAM R. WEBSTER, *Chairman.*
EDGAR MARBURG, *Secretary.*

American Steel and Wire Company,
F. H. Daniels.
Bethlehem Steel Company,
E. O'O. Acker.
Cambria Steel Company,
George E. Thackray.
Carnegie Steel Company,
W. A. Bostwick.
Robert A. Carter.
Central Iron and Steel Company,
James B. Bailey.
Charles S. Churchill.
James Christie.
F. H. Clark.
Albert Ladd Colby.
J. Allen Colby.
Colorado Fuel and Iron Company,
C. S. Robinson.
John Sterling Deans.
P. H. Dudley.
Franklin Institute,
Alex. E. Outerbridge, Jr.
J. E. Greiner.
Robert W. Hunt Company.
Illinois Steel Company,
P. E. Carhart.
Jones and Laughlin Steel Company,
Willis L. King.
E. F. Kenney.
Gaetano Lanza.
Lackawanna Steel Company,
F. E. Abbott.
Lukens Iron and Steel Company,
Charles L. Huston.
S. S. Martin.
John McLeod.
Richard Moldenke.
National Tube Company,
Frank N. Speller.
L. R. Pomeroy.
The Osborn Engineering Company,
Frank C. Osborn.
The Pennsylvania Steel Company,
J. V. W. Reynders.
Reading Iron Company.
Joseph T. Richards.
John A. Roebling's Sons Company,
H. J. Horne.
C. C. Schneider.
Shelby Steel Tube Company,
J. H. Nicholson.
J. P. Snow.
Standard Steel Works,
A. A. Stevenson.
J. A. L. Waddell.
Samuel T. Wagner.
Max H. Wickhorst.
H. V. Wille.
R. D. Wood and Company,
Walter Wood.

COMMITTEE B, ON STANDARD SPECIFICATIONS FOR CAST IRON AND FINISHED CASTINGS.

WALTER WOOD, *Chairman.*
RICHARD MOLDENKE, *Secretary.*

Hugh W. Adams.
James A. Beckett.
Robert Bentley.
Joseph W. Bramwell.
Colorado Fuel and Iron Company,
C. S. Robinson.
Albert Ladd Colby.
Edgar S. Cook.

COMMITTEE B.—*Continued.*

H. A. Croxton.
George M. Davidson.
H. E. Diller.
W. C. Du Comb.
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B. F. Fackenthal, Jr.
L. M. Fenner.
A. I. Findley.
Stanley G. Flagg, Jr.
W. K. Hatt.
J. A. Hays.
W. H. Hearne.
J. O. Henshaw.
P. S. Hildreth.
Henry M. Howe.
Illinois Steel Company, P. E. Carhart.
International Harvester Company, John G. Wood.
Robert Job.
Jones and Laughlin Steel Company, Willis L. King.
J. A. Kinkead.
Paul Kreuzpointner.
Gaetano Lanza.
William W. Lobdell.
A. E. Loudon.
Charles F. McKenna.
J. W. McQueen.
R. S. MacPherran.
Mansfield Merriman.
Tinius Olsen.
Alex. E. Outerbridge, Jr.
Leonard Peckitt.
L. S. Randolph.
David Reid.
Walter M. Saunders.
Albert Sauveur.
W. G. Scott.
C. W. Sherman.
Henry Souther.
H. W. Spangler.
Technischer Verein, Pittsburg, S. H. Stupakoff.
Enrique Touceda.
C. H. Vannier.
W. R. Webster.
Thomas D. West.
H. V. Wille.
N. B. Wittman.
F. W. Wood.
E. R. Wood, Jr.
I. H. Woolson.
C. H. Zehnder.

COMMITTEE C, ON STANDARD SPECIFICATIONS FOR CEMENT.

GEORGE F. SWAIN, *Chairman.*
GEORGE S. WEBSTER, *Vice-Chairman.*
RICHARD L. HUMPHREY, *Secretary.*

Booth, Garrett & Blair.
Spencer Cosby.
A. W. Dow.
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A. F. Gerstell.
Edward M. Hagar.
W. H. Harding.
Olaf Hoff.
W. J. Kelley.
Robert W. Lesley.
F. H. Lewis.
John B. Lober.
Andreas Lundteigen
Charles F. McKenna.
W. W. Maclay.
Charles A. Matcham.
A. W. Munsell.
National Fire Protection Association, Edward T. Cairns.
Spencer B. Newberry.
James Madison Porter.
Joseph T. Richards.
Clifford Richardson.
L. C. Sabin.
Harry J. Seaman.
Henry S. Spackman Engineering Company.
S. S. Voorhees.

COMMITTEE D, ON STANDARD SPECIFICATIONS FOR PAVING AND BUILDING BRICK.

LOGAN WALLER PAGE, *Chairman.*

Ira O. Baker.
Edward Orton, Jr.
W. D. Richardson.
Arthur N. Talbot.
Ira H. Woolson.

COMMITTEE E, ON PRESERVATIVE COATINGS FOR IRON AND STEEL.

S. S. VOORHEES, *Chairman.*
JOSEPH F. WALKER, *Secretary.*

W. A. Aiken.
James Christie.
The Joseph Dixon Crucible Company,
Malcolm MacNaughton.
Charles B. Dudley.
A. W. Dow.
C. N. Forrest.
Geo. Heckel.
International Acheson Graphite Company,
O. L. Collins.
Robert Job.
P. C. McIlliney.
Spencer B. Newberry.
J. R. Onderdonk.
W. A. Polk.
A. H. Sabin.
Wirt Tassin.
G. W. Thompson.
Wm. R. Webster.
J. W. Whitehead, Jr.
Max H. Wickhorst.
The A. Wilhelm Company,
Charles J. Davies.

COMMITTEE F, ON HEAT TREATMENT OF IRON AND STEEL.

HENRY M. HOWE, *Chairman.*

William Campbell.
Albert Sauveur.
Bradley Stoughton.

COMMITTEE G, ON THE MAGNETIC TESTING OF IRON AND STEEL.

J. WALTER ESTERLINE, *Chairman.*

W. J. Beck.
John A. Capp.
H. E. Diller.
Richard Moldenke.
J. A. Mathews.
C. E. Skinner.

COMMITTEE H, ON STANDARD TESTS FOR ROAD MATERIALS.

LOGAN WALLER PAGE, *Chairman.*
ARTHUR N. JOHNSON, *Secretary.*

Ira O. Baker.
W. H. Broadhurst.
A. W. Campbell.
A. Cushman.
A. W. Dow.
A. B. Fletcher.
W. S. Godwin.
W. K. Hatt.
G. B. Hemstreet.
J. A. Holmes.
Jos. W. Hunter.
C. A. Kenyon.
Frederic A. Kummer.
Nelson P. Lewis.
A. Marsten.
J. J. Morrow.
Clifford Richardson.
George W. Tillson
Calvin Tomkins.
E. O. Wallace.

COMMITTEE I, ON REINFORCED-CONCRETE.

F. E. TURNEAURE, *Chairman.*
R. W. LESLEY, *Vice-Chairman.*
RICHARD L. HUMPHREY, *Secretary.*

W. B. Fuller.
E. Lee Heidenreich.
A. L. Johnson.
Gaetano Lanza.
Edgar Marburg.
C. M. Mills.
L. S. Moisseff.
H. H. Quimby.
W. P. Taylor.
S. E. Thompson.
S. T. Wagner.
G. S. Webster.

COMMITTEE J, ON STANDARD SPECIFICATIONS FOR COKE.

C. H. ZEHNDER, *Chairman.*
RICHARD MOLDENKE, *Secretary.*

Warren Blauvelt.
W. H. Blauvelt.
Wm. A. Bole.
Edgar S. Cook.
D. T. Croxton.
John Donahoe.
Chas. B. Dudley.
D. T. Evans.
B. F. Fackenthal, Jr.
Geo. H. Finn.
H. L. Haldeman.
J. A. Holmes.
J. A. Kinkead.
John Lloyd.
Thomas Lynch.
T. D. Lynch.
W. C. Magee.
E. C. Means.
F. Schniewind.
W. G. Scott.
W. B. Snow.
Henry Souther.
D. B. Wentz.
H. V. Wille.
Walter Wood

COMMITTEE K, ON STANDARD METHODS OF TESTING.

GAETANO LANZA, *Chairman.*

Geo. A. Bostwick.
James Christie.
John S. Deans.
Chas. B. Dudley.
W. K. Hatt.
Henry M. Howe.
A. P. Hume.
Richard L. Humphrey.
Mansfield Merriman.
Richard Moldenke.
E. D. Nelson.
H. P. Talbot.
Geo. E. Thackray.
H. V. Wille.
Ira H. Woolson.

COMMITTEE L, ON STANDARD SPECIFICATIONS AND TESTS FOR CLAY AND CEMENT SEWER PIPES.

RUDOLPH HERING, *Chairman.*
A. J. PROVOST, JR., *Vice-Chairman.*
CHARLES F. MCKENNA, *Secretary.*

W. O. Foster.
F. C. Hitchcock.
W. O. Hull.
G. Kauffman.
J. O. Rossi.

COMMITTEE M, ON STANDARD SPECIFICATIONS FOR STAYBOLT IRON.

H. V. WILLE, *Chairman.*

F. B. Allen.
American Iron and Steel Manufacturing Company.
Brown and Company.
F. H. Clark.
J. A. Kinkead.
E. D. Nelson.
J. C. Ramage.

COMMITEE N, ON STANDARD TESTS FOR LUBRICANTS.

A. H. GILL, *Chairman.*
J. M. JEFFERS, *Secretary.*

Bureau of Standards,
S. W. Stratton.
Bureau of Steam Engineering, Navy Department,
W. M. Parks.
W. A. Converse.
W. M. Davis.
A. W. Dow.
J. L. Gray.
A. P. Hume.
E. D. Nelson.
J. H. Pew.
Geo. H. Taber.
C. E. Ward.

COMMITTEE O, ON UNIFORM SPEED IN COMMERCIAL TESTING.

PAUL KREUZPOINTNER, *Chairman.*
H. V. WILLE, *Secretary.*

W. A. Bostwick.
F. O. Bunnell.
H. H. Campbell.
A. P. Hume.
J. A. Kinkead.
S. M. Marshall.
Tinius Olsen.
A. A. Stevenson.

COMMITTEE P, ON FIRE-PROOFING MATERIALS.

IRA H. WOOLSON, *Chairman.*
R. P. MILLER, *Secretary.*

W. W. Ewing.
John R. Freeman.
H. W. Hodge.
Edwin Thacher.
D. E. Waid.
C. W. Somerville.

COMMITTEE Q, ON STANDARD SPECIFICATIONS FOR THE GRADING OF STRUCTURAL TIMBER.

HERMANN VON SCHRENK, *Chairman.*
W. K. HATT, *Secretary.*

C. R. Bangs
Chas. H. Davis.
A. O. Elzner.
Geo. H. Emerson.
B. E. Fernow.
R. S. Kellogg.
H. W. Lohmann.
R. A. Long.
A. J. Maclean
A. M. Mansfield.
A. F. Rosenheim.

COMMITTEE R, ON UNIFORM SPECIFICATIONS FOR BOILERS.

E. D. MEIER, *Chairman.*

F. B. Allen.
R. C. Carpenter.
J. H. Hartley.
Chas. L. Huston.
John McLeod.
Mutual Boiler Insurance Company,
R. S. Hale.
J. E. Sague.
H. V. Wille.

COMMITTEE S, ON WATERPROOFING MATERIALS.

W. A. AIKEN, *Chairman.*
A. W. DOW, *Secretary.*

Barrett Manufacturing Company,
W. S. Babcock.
E. W. DeKnight.
T. H. Ellis.
A. W. Munsell.
C. S. Reeve.
W. P. Taylor.
Maximilian Toch.
U. S. War Department,
Capt. Chester A. Harding.
Warren Brothers Company,
A. E. Schutte.

COMMITTEE T, ON THE TEMPERING AND TESTING OF STEEL SPRINGS AND STANDARD SPECIFICATIONS FOR SPRING STEEL.

J. A. KINKEAD, *Chairman.*

W. A. Bostwick.
F. O. Bunnell.
F. D. Carney.
J. C. Davis.
Nathan H. Davis.
Alan Lukens.
Archibald M. McCrea.
R. W. Mahon.
E. D. Nelson.
A. A. Stevenson
Max. H. Wickhorst.
H. V. Wille.

COMMITTEE U, ON STANDARD SPECIFICATIONS AND TESTS FOR WIRE ROPE.

(In course of organization.)

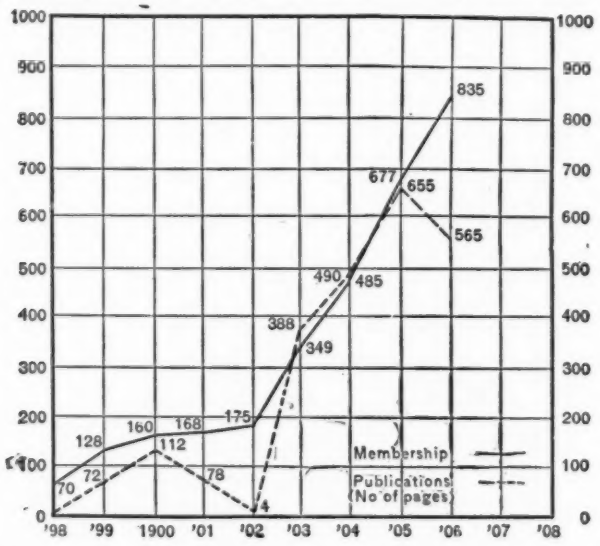
COMMITTEE V, ON THE CORROSION OF IRON AND STEEL.

(In course of organization.)

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE.

Since the Eighth Annual Meeting of the Society the Executive Committee has held three regular and one special meeting. One of these meetings was informal owing to the absence of a quorum. An abstract of the minutes of these meetings is appended to this report.

The record of the Society during the past year is highly gratifying. The membership has risen from 677 to 835, and is confidently expected to reach a thousand by the next annual



meeting. For the first time in its history the Society has attained to a plane of financial independence. In its last annual report the Executive Committee announced that it had not been found necessary to issue a general appeal for subscriptions, but that the Society was still dependent in no small measure on its contributing members and special subscribers for its financial maintenance. At the beginning of the present fiscal year the contributing members were notified that their support during

the present year would probably not be required. It now appears certain that this expectation will be realized, and that an amendment of the by-laws looking to the abrogation of the special class of contributing members may be safely proposed at the next annual meeting. The marked improvement in the financial status of the Society is attributable partly to the substantial growth of membership, and partly to the effect of the amendment of the by-laws adopted last year by which membership in the International Association has been made voluntary instead of obligatory, and the dues of members connected with the International Association have been increased from $5.00 to $6.50 per annum. Prior to this change the Society was obliged to remit to the International Association $1.50 out of the dues of each member wholly irrespective of whether the member really desired to be connected with that Association. On the basis of present membership this would mean an annual remittance of about $1,250 which now remains in the treasury of the Society.

The Executive Committee regards this time a particularly fitting one to place on record its sense of grateful recognition of the generous support that the Society has received at the hands of its contributing members and special subscribers during a period of its existence when without such aid its financial maintenance would not have been possible.

The Executive Committee deems it highly desirable that steps should be taken towards the publication in a separate volume of the standard specifications adopted by the Society. Eighteen such specifications are now available, and others are in course of preparation. A special meeting was held last fall to confer with the publisher of the Engineering Standards Committee of Great Britain. These negotiations, however, have not led to a satisfactory issue. It is believed that the cost of publishing such a volume, of which revised editions should be issued as frequently as may be found necessary, could be readily covered by the proceeds of sales, and that it might in fact be expected to yield a substantial revenue to the Society.

The statistics of the year are given in more detailed form below:

Membership.—The membership at the last annual meeting was 677. Since then 199 new applications for membership have

been received and approved. The Society has suffered a loss of two members through death: H. Winfield Wyman died on November 11, 1905, and Edward Atkinson on December 11, 1905. The number of resignations for the year is 22, and 17 members have been dropped for arrears in dues. The total loss from all causes is 41, leaving a net gain of 158, and making the total membership at present 835.

Publications.—In addition to the annual volume of the Proceedings (Vol. V, 565 pp.), a pamphlet of 103 pages, containing the list of members and other information of a general nature concerning the Society, was issued as well as seven official circulars of information.

New Committees.—With a view to their assistance in the formulation of programs for meetings, and in the furtherance of committee work in their respective spheres, the Executive Committee has appointed the following Advisory Committees:

On Iron and Steel—Wm. R. Webster, Chairman; H. H. Campbell, H. V. Wille.

On Cast Iron—Richard Moldenke, Chairman; Henry Souther, Thos. D. West.

On Cement and Concrete—Clifford Richardson, Chairman; Richard L. Humphrey, Spencer B. Newberry.

On Brick and Terra-Cotta Products—Edward Orton, Jr., Chairman; H. O. Hofman, W. D. Richardson.

On Preservative Coating—G. W. Thompson, Chairman; Robert Job, S. S. Voorhees.

On Tests and Testing Apparatus—Gaetano Lanza, Chairman; Mansfield Merriman, Tinius Olsen.

Partly in pursuance of action at the last annual meeting and partly at the initiative of the Executive Committee, the list of technical committees has been increased as follows:

Committee S.—On Waterproofing Materials.

Committee T.—On the Tempering and Testing of Steel Springs and Standard Specifications for Spring Steel.

Committee U.—On Standard Specifications and Tests for Wire Rope.

Finances.—The improved financial condition of the Society, and the causes to which the same is attributable have been pre-

viously referred to. The cash balance is $495.18 and there are no unpaid bills on hand. In pursuance of a resolution passed at the last annual meeting, a contribution of $100 was made to the general funds of the International Association.

ANNUAL REPORT OF THE TREASURER.

From June 10, 1905, to June 15, 1906.

RECEIPTS.

Membership dues	$4,292 91	
Contributing Membership dues (1905)	50 00	
Collections for account International Association	693 50	
Sale of publications	478 51	
Orders for binding	266 00	
Reprints	153 86	
Excess remittances	65 77	
Interest on deposits	18 99	
Total receipts	$6,019 54	
Cash balance June 10, 1905	604 85	
		$6,624 39

DISBURSEMENTS.

Remitted to International Association, Dues, etc.	$ 594 28	
Expenses, International Association	96 72	
Subscription, International Association	100 00	
Printing, engraving, binding, etc	2,986 87	
Secretary's salary to July 1, 1906	1,500 00	
Clerical services	471 13	
Expenses, Secretary's office	193 93	
Stenographer, Eighth Annual Meeting	87 66	
Committee expenses	52 12	
Excess remittances refunded	46 50	
Total disbursements	$6,129 21	
Cash balance, June 15, 1906	495 18	
		$6,624 39

Relations with the International Association for Testing Materials.—Of the 835 members of the American Society, 247 have signified their desire to hold membership also in the International Association. It is hoped that this number will be largely increased before the next Congress which will be held, as previously announced, at Brussels, September 3–8, 1906. Such members are entitled to free copies in English of all official matter presented at the Congress in the form of reports of technical

committees and referees. Fifteen such reports are already in print and as many more are promised. The Association has incurred considerable expense in the translating and printing of these reports which are in part of great scientific interest and value, and entirely disproportionate to the moderate membership dues of $1.50 per annum. Members may also obtain the non-official papers, printed in their original language only, followed by abridged summaries in two other languages. Twenty-one original papers and eight abstracts of papers previously published elsewhere are in hand, and five additional papers are promised. The subscription price is $2.50 for the set. Those participating in the Congress will receive these papers without extra charge beyond the fixed subscription fee of $5 for the general privileges of the Congress.

Respectfully submitted on behalf of the Executive Committee

EDGAR MARBURG, *Secretary-Treasurer.*

CHARLES B. DUDLEY, *President.*

REPORT OF AUDITING COMMITTEE.

PHILADELPHIA, July 2, 1906.

To the Executive Committee of the American Society for Testing Materials:

We have examined the books and accounts of the Secretary-Treasurer from January 2, 1906, the date of the last audit, to June 15, 1906, the date of the annual report of the Treasurer, and find the cash balance of $495.18 to be correct.

[Signed] R. W. LESLEY,
J. A. COLBY,
Auditing Committee.

APPENDIX.

ABSTRACT OF MINUTES OF THE EXECUTIVE COMMITTEE.

REGULAR MEETING, October 7, 1905.—Engineers' Club of Philadelphia, 1122 Girard Street, Philadelphia, Pa. Present: Messrs. Dudley, Christie, Bostwick and Marburg of the Executive Committee and Mr. Wm. R. Webster on invitation.

The action taken at the last quarterly meeting on June 24, in the absence of a quorum, was duly approved.

The Secretary reported the receipt of 76 applications for membership, duly approved, and the resignation of one member, making the total membership 752.

The Secretary reported that the letter-ballot on the amendment of Article I, Sections 1, 2, and 3 and Article IV, Section 2, of the By-Laws had resulted in 86 affirmative and 1 negative vote.

The Secretary further reported the returns from the letter-ballot on the adoption of the following specifications:

	For.	Against
For Structural Steel for Bridges	60	6
For Steel Castings	63	2
For Steel Axles	61	4
For Steel Forgings	60	3
For Cast Iron Car Wheels	60	3
For Gray Iron Castings	62	2

The following action was taken on matters referred to the Executive Committee at the Eighth Annual Meeting:

1. The amount of the contribution to the general funds of the International Association for the current year was fixed at $100.00.
2. The proposed appointment of committees on (*a*) Waterproofing Materials and (*b*) on Tempering and Testing of Steel Springs and Standard Specifications for Spring Steel, was approved.
3. In the matter of appointing a committee on "The Formulation of a Plan for Making Such Scientific Tests of Structural Steel as Seem Likely to be of Advantage to the Engineering Profession," it was decided to refer this subject to Committee K on Standard Methods of Testing with the recommendation that it be referred to a special sub-committee under the chairmanship of Professor Mansfield Merriman.
4. The question of arrangements for headquarters of the Society was referred with power to a committee consisting of Mr. James Christie, Mr. Robert W. Lesley and the Secretary.

In pursuance of a suggestion received from Mr. Paul Kreuzpointner it was decided to appoint a committee on Standard Specifications and Tests for Wire Rope.

It was decided to appoint advisory committees of three, consisting each of a chairman and two members, in connection with the principal interests represented in the membership in order that these committees may co-operate with the Executive Committee in the formulation of the program for meetings and in the furtherance of the work of the technical committees in their respective fields.

The Secretary reported that 467 replies had been received to the circular inquiry respecting continuation of membership in the International Association, of which 204 were for and 263 against continuation.

It was decided that dues for the current year in the International Association shall be remitted only for those members who propose to continue their connection with the International Association.

SPECIAL MEETING, December 2, 1905.—Engineers' Club of Philadelphia, 1122 Girard Street, Philadelphia, Pa. Present: Messrs. Dudley, Lesley, Christie and Marburg.

The Secretary submitted a preliminary draft of a proposed agreement between the Society and Mr. Robert Atkinson for the publication in book form of the standard specifications adopted by the Society. This proposed agreement was adopted in slightly amended form and the Secretary was instructed to obtain legal services in the preparation of the formal agreement.

REGULAR MEETING, January 6, 1906.—Engineers' Club of Philadelphia, 1122 Girard Street, Philadelphia, Pa. Present: Messrs. Dudley, Lesley, Christie, McLeod and Marburg.

The Secretary reported the receipt of 44 applications for membership, duly approved; the loss of one member by the death of Edward Atkinson which occurred on December 11, 1905, and the resignation of seven members, making the total membership 788.

The Committee on permanent headquarters for the Society reported that the Board of Directors of the Engineers' Club of Philadelphia had courteously placed the club house at the disposal of the Society for purposes of committee meetings and had extended the privileges of the club house to the members of the Society coming within the non-resident rule of the Engineers' Club. A vote of thanks was passed in acknowledgment of this courtesy.

The Secretary submitted the proposed agreement in legal form with Mr. Robert Atkinson for the publication of the standard specifications of the Society which was adopted with slight amendment.

REGULAR MEETING, April 7, 1906.—Engineers' Club of Philadelphia, 1122 Girard Street, Philadelphia, Pa. Present: Messrs. Dudley, Lesley, Christie and Marburg.

The Secretary reported the receipt of 33 applications for membership, duly approved; the resignation of 14 members; the dropping of 17 members on account of arrears in dues and the loss of one member by the death of W. H. Wyman, which occurred on November 11, 1905; making the total membership 789.

The Secretary submitted a letter from the International Association dated February 27, 1906, announcing that the next Congress would be held at Brussels, September 3-8, 1906, and expressing the hope that every effort would be made in this country to increase the membership of the Association. The Secretary was instructed to call attention in the next Circular to Members to the advantages attached to membership in the International Association.

LIST OF PUBLICATIONS.

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NOTE.—The Society, from its organization in 1898 till its incorporation under its present name in 1902, was designated the American Section of the International Association for Testing Materials. During this period twenty-eight (28) Bulletins were issued, which, collectively, constitute Volume I. of the Proceedings. In 1902 it was decided to publish the Proceedings in the form of annual volumes. Volume II. is the first volume of this new series.

VOLUME I.

Bulletin No. 1. Minutes of the Organization Meeting, June 16, 1898. Minutes of the Executive Committee, June 25, 1898, to February 22, 1899. Minutes of First Annual Meeting, August 27, 1898. April 1899. Pp. 1–8.

Bulletin No. 2. Provisional Program for the Second Annual Meeting. July, 1899. Pp. 9–12.

Bulletin No. 3. Officers of the American Section. Program of the Second Annual Meeting. August, 1899. Pp. 13–16.

Bulletin No. 4. The work of the International Association for Testing Materials. Annual Address by the Chairman, Professor Mansfield Merriman. September, 1899. Pp. 17–26.

Bulletin No. 5. Preliminary Report on the Present State of Knowledge Concerning Impact Tests, by Professors W. Kendrick Hatt and Edgar Marburg. October, 1899. Pp. 27–52.

Bulletin No. 6. Report of Second Annual Meeting, August 15–16, 1899. Minutes of the Executive Committee to August 16, 1899. November 1899. Pp. 53–72.

Bulletin No. 7. Minutes of the Executive Committee to January 6, 1900. Miscellaneous Announcements. January, 1900. Pp. 73–80.

Bulletin No. 8. Proposed Standard Specifications for Structural Steel for Bridges and Ships. May, 1900. Pp. 81–86.

Bulletin No. 9. Proposed Standard Specifications for Structural Steel for Buildings. May, 1900. Pp. 87–92.

Bulletin No. 10. Proposed Standard Specifications for Open-hearth Boiler Plate and Rivet Steel. May, 1900. Pp. 93–100.

Bulletin No. 11. Proposed Standard Specifications for Steel Rails. May, 1900. Pp. 101-106.

Bulletin No. 12. Proposed Standard Specifications for Steel Splice Bars. May, 1900. Pp. 107-110.

Bulletin No. 13. Proposed Standard Specifications for Steel Axles. May, 1900. Pp. 111-114.

Bulletin No. 14. Proposed Standard Specifications for Steel Tires. May, 1900. Pp. 115-118.

Bulletin No. 15. Proposed Standard Specifications for Steel Forgings. May, 1900. Pp. 119-124.

Bulletin No. 16. Proposed Standard Specifications for Steel Castings. May, 1900. Pp. 125-128.

Bulletin No. 17. Proposed Standard Specifications for Wrought Iron. May, 1900. Pp. 129-134.

Bulletin No. 18. Report of the American Branch of International Committee No. 1. May, 1900. Pp. 135-144.

Bulletin No. 19. Program of the Third Annual Meeting. Minutes of the Executive Committee, April 7, 1900. Correspondence Relating to the Representation of the American Section of the International Council. September, 1900. Pp. 145-172.

Bulletin No. 20. Progress Report of the American Branch of International Committee No. 1. October, 1900. Pp. 173-184.

Bulletin No. 21. Announcement of International Congress of 1901. Report of Third Anual Meeting, October 25-27, 1900. Minutes of the Executive Committee to January 5, 1901. Officers of the American Section for 1900-02. March, 1901. Pp. 185-214.

Bulletin No. 22. Program of the Fourth Annual Meeting. May, 1901. Pp. 215-216.

Bulletin No. 23. List of Members of the American Section. By-Laws of the American Section. June, 1901. Pp. 217-230.

Bulletin No. 24. Revised Standard Specifications for Wrought Iron. June, 1901. Pp. 231-236.

Bulletin No. 25. Report of the American Branch of International Committee No. 1. June, 1901. Pp. 237-244.

Bulletin No. 26. Letter Ballot on Proposed Standard Specifications. July, 1901. Pp. 245-246.

Bulletin No. 27. Report of Fourth Annual Meeting, June 29, 1901. August, 1901. Pp. 247-262.

Bulletin No. 28. Program of the Fifth Annual Meeting. May, 1902. Pp. 263-266.

VOLUME II.

Summary of Proceedings of the Fifth Annual Meeting.

Annual Address by the Retiring President, Henry M. Howe.

Proposed Modifications of the Standard Specifications for Steel Rails Topical Discussion.

Is it Desirable to Specify a Single Grade of Structural Steel for Bridges of Ordinary Spans? Topical Discussion.
Formal Discussion: A. P. Boller, T. L. Condron, Theodore Cooper, J. E. Greiner, John McLeod, C. C. Schneider, J. P. Snow.
Rail Temperatures. Simon Strock Martin.
Finishing Temperature and Structure of Steel Rails. Albert Sauveur.
The Relation between the Basic Open-hearth Process and the Phy.ical Properties of Steel. Topical Discussion.
Steel Rivets. Gaetano Lanza.
The Ethics of Testing. Paul Kreuzpointner.
Standard Cement Specifications. R. W. Lesley.
The Advantages of Uniformity in Specifications for Cement and Methods of Testing. George S. Webster.
The Chemical Analysis of Cement: Its Possibilities and Limitations. Richard K. Meade.
Cement Testing in Municipal Laboratories. Richard L. Humphrey.
Tests of Reinforced Concrete Beams. W. Kendrick Hatt.
Effect of Variation in the Constituents of Cast Iron. W. G. Scott.
Present Status of Testing Cast Iron. Richard G. Moldenke.
The Need of Foundry Experience for the Proper Inspection and Testing of Cast Iron. Thos. D. West.
A Quick and Automatic Taper-Scale Test. Asa W. Whitney.
High Strength of White Iron Castings as Influenced by Heat Treatment. Alex. E. Outerbridge, Jr.
Notes on Current Specifications for Cast Iron Pipe. Walter Wood.
On the Constitution of Cast Iron. Henry M. Howe.

APPENDICES.

Appendix I. Report on the Buda-Pesth Congress. Henry M. Howe.
Appendix II. Bibliography on Impact Tests and Impact Testing Machines. W. Kendrick Hatt and Edgar Marburg.
Appendix III. Rules for Standard Tests of Materials Formulated by the German Association for Testing Materials (English Translation).

VOLUME III.

Summary of Proceedings of the Sixth Annual Meeting.
The Making of Specifications—Annual Address by the President, Charles B. Dudley.
Report of Committee A on Standard Specifications for Iron and Steel.
Report of Committee B on Standard Specifications for Cast Iron and Finished Castings.
Report of Committee C on Standard Specifications for Cement.
Report of Committee E on Preservative Coatings for Iron and Steel.
Report of Committee G on the Magnetic Properties of Iron and Steel.

Specifications for Iron and Steel Structures Adopted by the American Railway Engineering and Maintenance of Way Association, in March, 1903, with Introduction by J. P. Snow, Chairman.

Specifications for Locomotive Axles and Forgings, Recommended by a Committee of the American Railway Master Mechanics' Association, in June, 1903, with Introduction by F. H. Clark, Chairman.

Specifications for Steel Rails Adopted by the American Railway Engineering and Maintenance of Way Association, in March, 1902, and the Modifications Submitted in March, 1903; William R. Webster, Chairman.

Specifications for Boiler Plate, Rivet Steel, Steel Castings, and Steel Forgings, Recommended by a Committee of the American Society of Mechanical Engineers; H. W. Spangler, Chairman.

Manufacturers' Standard Specifications as Revised in February, 1903, and Their Comparison with Other Recent Prominent Specifications. Albert Ladd Colby.

The Requirements for Structural Steel for Ship-building Purposes. Topical Discussion, opened by E. Platt Stratton.

Springs and Spring Steels. William Metcalf.

The Rolling of Piped Rails. Topical Discussion, opened by Albert Sauveur and Robert Job.

The Casting of Pipeless Ingots by the Sauveur Overflow Method. Albert Sauveur and Jasper Whiting.

Nickel Steel: Its Properties and Applications. Albert Ladd Colby.

Alternate Stresses in Bridge Members. Gustav Lindenthal.

The Constitution of Cast Iron. William Campbell.

Machine-cast Sandless Pig Iron in Relation to the Standardizing of Pig Iron for Foundry Purposes. Edgar S. Cook.

The Physical Properties of Malleable Castings as Influenced by the Process of Manufacture. Richard G. Moldenke.

Cast Iron: A Consideration of the Reactions Which Make it Valuable. Herbert E. Field.

The Importance of Adopting Standard Sizes of Test Bars for Determining the Strength of Cast Iron. Alexander E. Outerbridge, Jr.

The Demand for a Specified Grade of Cast Iron. W. G. Scott.

Cast Iron for Dynamo and Motor Frames. H. E. Diller.

The Light Aluminum Alloys. J. W. Richards.

The Testing of Bearing Metals. G. W. Clamer.

The Master Car Builders' Drop-testing Machine as Installed at Purdue University. W. F. M. Goss.

Stremmatograph Tests of Unit Fiber Strains and Their Distribution in the Base of Rails under Moving Locomotives, Cars, and Trains. P. H. Dudley.

The Control of the Finishing Temperature of Steel Rails by the Thermomagnetic Selector. Albert Sauveur and Jasper Whiting.

A Direct-reading Apparatus for Determining the Energy Losses in Transformer Iron. J. Walter Esterline.

The United States Road Material Laboratory: Its Aims and Methods. L. W. Page and A. Cushman.

A Preliminary Program for the Timber Test Work to be Undertaken by the Bureau of Forestry, United States Department of Agriculture. W. K. Hatt.

A Brief Account of the History and Methods of the International Railway Congress. P. H. Dudley.

The Testing of Bitumens for Paving Purposes. A. W. Dow.

Soundness Tests of Portland Cement. W. P. Taylor.

Portland Cement Mortar Exposed to Cold. C. S. Gowen.

Some Observations on the Effect of Water and Combinations of Sand upon the Setting Properties and Tensile Strength of Portland and Natural Cements. E. S. Larned.

Tests on the Compressive Strength of Concrete and Mortar Cubes. C. H. Umstead.

VOLUME IV.

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The Influence of Specifications on Commercial Products—Annual Address by the President, Charles B. Dudley.

Report of Committee A on Standard Specifications for Iron and Steel. Discussion.

Report of Committee B on Standard Specifications for Cast Iron and Finished Castings.

1. Proposed Standard Specifications for Foundry Pig Iron.
   Chemical Specifications for Pig Iron. B. F. Fackenthal.
   Specifications for Cast Iron and Finished Castings. Richard Moldenke.
2. Proposed Standard Specifications for Cast Iron Pipe and Special Castings.
3. Proposed Standard Specifications for Locomotive Cylinders.
4. Proposed Standard Specifications for Cast Iron Car Wheels.
5. Proposed Standard Specifications for Malleable Castings.
6. Proposed Standard Specifications for Gray Iron Castings.

Standard Specifications for Foundry Pig Iron, as adopted November 14, 1904.

Report of Committee C on Standard Specifications for Cement.

Report of Committee E on Preservative Coatings for Iron and Steel.

Report of Committee G on the Magnetic Testing of Iron and Steel.

Report of Committee H on Standard Tests for Road Materials.

Specifications for Steel Rails, American Railway Engineering and Maintenance of Way Association, as Amended and Adopted in March, 1904; Wm. R. Webster, Chairman.

Specifications for Iron and Steel Structures, American Railway Engineering and Maintenance of Way Association, as Amended and Adopted in March, 1904; J. P. Snow, Chairman.

Comparison of the Specifications for Axles and Forgings, Proposed by Committees of the American Railway Master Mechanics' Association and the American Society of Mechanical Engineers, with the Standard Specifications Adopted by the American Society for Testing Materials. H. V. Wille.

Alloy Steels. William Metcalf.

A Brief Review of the Status of Testing in the United States. Gaetano Lanza.

The Early Use of 60,000-pound Steel in the United States. Samuel Tobias Wagner.

The Classification of Iron and Steel. Albert Sauveur.

A Proposed Test for Detecting Brittleness in Structural Steel. J. P. Snow.
Appendix. Experimental Studies of the Causes of Brittleness of Steel. Ch. Fremont.

Tests for Detecting Brittle Steel. Wm. R. Webster.

Tensile Impact Tests of Steel. W. K. Hatt.

Staybolt Iron and Machine for Making Vibratory Tests. H. V. Wille.

Bending Moments in Rails. P. H. Dudley.

The Desirability of a Uniform Speed for Commercial Testing. Paul Kreuzpointner.

Cast Iron: Strength, Composition, Specifications. W. J. Keep.

Pig Iron Feasts and Famines: Their Causes and How to Regulate Them George H. Hull.

Structure of Alloys.. William Campbell.

A New Chuck for Holding Short Test Pieces. T. D. Lynch.

The Commercial Testing of Sheet Steel for Electrical Purposes. C. E. Skinner.

Permeability of Cast Steel. H. E. Diller.

Specifications for Air-Brake Hose. Max H. Wickhorst.

The Effects of Preservative Treatments on the Strength of Timber. F. A. Kummer.

Results of an Investigation Concerning Causes of Durability of Paints for Structural Work. Robert Job.

Preservative Coatings for Iron and Steel. Cyril de Wyrall.

Some Statistics of the Cement Industry in America. R. W. Lesley.

Practical Cement Control. Charles W. McKenna.

Some Possible By-Products in the Portland Cement Industry. Clifford Richardson.

Some Notes on the Boiling Test for Cement. Frederick H. Lewis.

Tests of Reinforced Concrete Beams: A. N. Talbot, F. E. Turneaure, Edgar Marburg.
Discussion of the three preceding papers.

The Mechanical Defects of Sieves Used in Determining the Fineness of Cement. E. W. Lazell.

Some Attempts to Limit the Personal Equation in Cement Testing. W. A. Aiken.

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Summary of Proceedings of the Eighth Annual Meeting.

The Testing Engineer—Annual Address by the President, Charles B. Dudley

Report of Committee A on Standard Specifications for Iron and Steel, embodying recommendations for the revision of the Standard Specifications for (1) Structural Steel for Bridges, (2) Steel Rails, (3) Steel Castings, (4) Steel Axles and (5) Steel Forgings.

Summary of Action on Report of Committee A on Standard Specifications for Iron and Steel.

Standard Specifications for Structural Steel for Bridges.

Standard Specifications for Steel Castings.

Standard Specifications for Steel Axles.

Standard Specifications for Steel Forgings.

Report of Committee B on Standard Specifications for Cast Iron and Finished Castings, embodying the proposed Standard Specifications for (1) Car Wheels and (2) Gray Iron Castings.

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Report of Committee E on Preservative Coatings for Iron and Steel.

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Report of Committee R on Boiler Inspection.

Some Causes of Failure of Rails in Service—Robert Job.

Rail Sections as Engineering Structures—P. H. Dudley.

Influence of Methods of Piling Staybolt Iron on Vibratory Tests—H. V. Wille.

A Preliminary Report on the Effect of Combined Stresses on the Elastic Properties of Steel—E. L. Hancock.

A Comparison of Standard Methods of Testing Cast Iron—Richard Moldenke.

The Thermit Process in American Practice—E. Stuetz.

Pig Iron Grading by Analysis—Hambden Buel.

Hard Cast Iron: The Theory of One of its Causes—Henry Souther.

Plan and Scope of the Proposed Investigation of Structural Materials Under the Auspices of the U. S. Geological Survey—J. A. Holmes and Richard L. Humphrey.

A Laboratory Course in Testing Materials of Construction—W. K. Hatt.

An Elementary Course in Properties of Materials—G. L. Christensen.

A Large Hydraulic Testing Machine for Uniform Loads—Robert A. Cummings.

Specifications for **Cotton Tapes** for Electrical Purposes—R. D. DeWolf.

The Rattler Test for Paving Brick as a Safe Method of Disclosing the Limit of Permissible Absorption—Edward Orton, Jr.

Normal Consistency Tests of Neat Cement—R. S. Greenman.

Economical Mold for Forming Compressive Test Pieces for Concrete—Clifford Richardson and C. N. Forrest.

Low-pulling, Early-stage Portland Cement *vs.* the Ordinary Early-strength-developing Product—W. A. Aiken.

Investigation of the Effect of Heat Upon the Crushing Strength and Elastic Properties of Concrete—Ira H. Woolson.

British Standard Specifications for Portland Cement, with Introduction—R. W. Lesley.

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The Collective Portland Cement Exhibit and Model Testing Laboratory of the Association of American Portland Cement Manufacturers and the Results of Tests at the Louisiana Purchase Exposition, St. Louis, Mo.—Richard L. Humhprey.

Proper Methods in Conducting Painting Tests—G. W. Thompson.

The Practicability of Establishing Standard Specifications for Preservative Coatings for Steel—Topical Discussion.

Protection of Iron and Steel Structures by Means of Paper and Paint—Louis H. Barker.

What is the Best Method of Painting Steel Cars? Frank P. Cheesman

The Effect of Electricity on Paint—James C. Blanch.

Ludwig von Tetmajer—Memoir.

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STANDARD SPECIFICATIONS

ADOPTED BY THE

AMERICAN SOCIETY FOR TESTING MATERIALS.

NOTE:—The formulation and adoption of Standard Specifications for the various materials of engineering is one of the important functions of the Society. These specifications are revised from time to time to meet changed conditions.

The following complete list of Standard Specifications, in their latest revised form, is here given for convenience of reference:

1. Standard Specifications for Structural Steel for Bridges, Vol. V, pp. 48–52.
2. Standard Specifications for Structural Steel for Ships, Vol. I, pp. 81–86, Bulletin, No. 8.
3. Standard Specifications for Structural Steel for Buildings, Vol. I, pp. 87–92, Bulletin, No. 9.
4. Standard Specifications for Open Hearth Boiler Plate and Rivet Steel, Vol. I, pp. 93–100, Bulletin, No. 10.
5. Standard Specifications for Steel Rails, Vol. I, pp. 101–106, Bulletin, No. 11.
6. Standard Specifications for Steel Splice Bars, Vol. I, pp. 107–110, Bulletin, No. 12.
7. Standard Specifications for Steel Axles, Vol. V, pp. 56–58.
8. Standard Specifications for Steel Tires, Vol. I, pp. 115–118, Bulletin, No. 14.
9. Standard Specifications for Steel Forgings, Vol. V, pp. 59–62.
10. Standard Specifications for Steel Castings, Vol. V, pp. 53–55.
11. Standard Specifications for Wrought Iron, Vol. I, pp. 231–236, Bulletin, No. 24.

12. Standard Specifications for Foundry Pig Iron, Vol. IV, pp. 103–104.
13. Standard Specifications for Cast Iron Pipe and Special Castings, Vol. IV, pp. 57–66.
14. Standard Specifications for Locomotive Cylinders, Vol. IV, pp. 69–70.
15. Standard Specifications for Cast Iron Car Wheels, Vol. V, pp. 65–70.
16. Standard Specifications for Malleable Castings, Vol. IV, pp. 95–96.
17. Standard Specifications for Gray Iron Castings, Vol. V, pp. 71–74.
18. Standard Specifications for Cement, Vol. IV, pp. 107–110.

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INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

BY-LAWS.

Adopted at the Buda-Pesth Congress, 1901

SECTION 1. The Association shall be called "THE INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS."

SEC. 2. The objects of the Association are: the development and unification of standard methods of testing; the investigation of the technically important properties of the materials of construction and other materials of technical importance, and also the perfecting of apparatus used for this purpose.

These objects will be furthered:

1. By the Congresses and other meetings of the Association.
2. By the publication of an official Journal.
3. By any other means that may appear desirable.

SEC. 3. The funds necessary for carrying out the purposes mentioned in Section 2 will be raised by

1. The annual subscriptions of members.
2. Profits from the official Journal.
3. Other contributions.

SEC. 4. Any person may become a member upon being proposed by two members of the Association.

Official bodies and technical societies can be elected directly on their sending in their application for membership.

Applications for membership must be sent in writing to the President or to a member of the Council.

Resignations of membership must be sent in the same way.

SEC. 5. It is the duty of every member to further the interests of the Society to the best of his ability.

Every member is required to pay an annual subscription of at least 6 Mks.=6 shillings=$1.50.*

The Council is authorized to increase the annual subscription in order to cover extraordinary expenses incurred in the interests of the Association.

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*Subscriptions are to be paid to the duly appointed collectors in each country, the card of membership serving as a receipt. Subscriptions not paid by the first of July are collected through the post-office.

SEC. 6. Every member has the right to obtain the Journal of the Association, during the period for which his subscription has been paid, on paying the fixed reduced price.*

SEC. 7. The Association will hold a Congress, as a rule, every second year.

The arrangements for the Congresses will be discussed at general meetings and in meetings of the different sections.

Sections will be formed for the different groups of materials as may be considered necessary.

At present there are three sections:

I. Metals.

II. Natural and artificial building stones, cements and mortars.

III. Other materials of technical value.

Any special questions relating to the subjects of the different sections will be considered at sectional meetings.

The members assisting at the sectional debates, under the presidency of a member of the Council, will appoint the governing bodies of the different sections.

The results of the deliberations of the different sections must be communicated at a general meeting which will pass resolutions embodying the proposals of the sections.

Reports of Commissions, proposals of the Council and other matters to be laid before the Congress, will be printed in German, French and English, and will be sent (in the language preferred) to all members who have announced their intention of taking part in the Congress, within fourteen days before the meeting of the Congress, if possible.

The decisions of the Congress will be printed in all three languages and sent to all members of the Association.

SEC. 8. The Council of the Association will transact all necessary business connected with the Association.

The Council will consist of the President and the duly elected members.

Every country represented in the Association by at least twenty members has the right to propose one member as member of the Council.

The President will be elected by the Congress, the Council by the members belonging to the different countries.

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* The reduced price has been fixed at 10 Mks.= 10 shillings = $2.50. This sum may be sent in with the subscriptions. The yearly volumes begin on January 1.

Till such election has taken place the former members of the Council remain in office.

The names of proposed new members of the Council have to be communicated to the President before each Congress.

The two Vice-Presidents will be elected by the Council from among its own members.

The Council is entitled to transact business when it has been duly called together according to rule and when the President or one of the Vice-Presidents is present.

Members of the Council may be re-elected.

If a member of the Council resigns during his term of office, the President shall immediately direct the election of a substitute by the members belonging to the country in question.

In the event of the death or resignation of the President, the Council will appoint one of its members to carry on the presidential duties till the next Congress.

The term of office of the Council lasts from one Congress till the next.

SEC. 9. The business of the Association will be attended to by the President, assisted by a paid Secretary.

The members of the Council will attend to the business of the Association in the country which they represent.

SEC. 10. The resolutions of the Congresses on technical questions merely serve to express the opinion of the majority. They are therefore in the form of recommendations and are in no way binding.

SEC. 11. The resolutions of the Congresses can only be carried if at least three-fourths of the recorded votes are in favor of them. Every member of the Association present, as well as every representative of official bodies and technical societies, has one vote.

The rights and duties of a member of the Association are not altered by the fact of his belonging at the same time to a national or other Association which Association is itself a member of the International Association.

SEC. 12. The technical problems to be considered by the Association will be decided upon by the Congresses and by the Council and will be duly referred to commissions or reporters appointed by the Council.

SEC. 13. The Council draws up its own regulations according to the By-Laws of the Association and to the needs which may from time to time present themselves.

SEC. 14. In the event of the Association being dissolved, any funds belonging to it will be handed over to the "International Red Cross Association."

THE INTERNATIONAL ASSOCIATION FOR TESTING MATERIALS.

Technical Problems, Committees* and Referees.

As constituted in August, 1905.

SECTION A.

METALS.

Problem 1.—On the basis of existing specifications, to seek methods and means for the introduction of international specifications for testing and inspecting iron and steel of all kinds. (Proposed at the Zurich Congress, 1895.)

Committee:

Chairman, A. Rieppel, Aeussere Cramer-Klettstrasse 12, Nuremburg, Germany.

Vice-Chairman, G. Alpherts, Koninginnegracht 66, Hague, Holland.

American Members, H. H. Campbell, James Christie, Carnegie Steel Company, represented by W. A. Bostwick; Franklin Institute, represented by A. E. Outerbridge, Jr., Paul Kreuzpointner, R. Moldenke, W. R. Webster, Walter Wood.

Problem 2.—To establish methods of inspection and testing for determining the uniformity of individual shipments of iron and steel. (Proposed at the Stockholm Congress, 1897.)

Committee:

Chairman, W. Ast, Nordbahnhof, Vienna, Austria.

Vice-Chairman (office vacant).

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* The names of only the Chairmen, the Vice-Chairmen, and American Members of International Committees are here given.

American Members, Booth, Garrett and Blair, Thos. Gray, Gus. C. Henning, Paul Kreuzpointner, A. A. Stevenson, W. R. Webster, Albert Sauveur.

Problem 4.—Methods for testing welds and weldability. (Proposed at the Zurich Congress, 1895.)
Referee, R. Krohn, Danzig, Germany.

Problem 5.—Collection of data for establishing standard rules for piece tests, with special reference to axles, tires, springs, pipes, etc. (Proposed at the Zurich Congress, 1895.)

Committee:

Chairman, W. Rayl, Nordbahnstrasse 50, Vienna, II, Austria.
Vice-Chairman, A. Sailler, Favoritenstrasse 20, Vienna, IV, Austria.
American Members, M. H. Wickhorst, H. V. Wille.

Problem 6.—On the most practical methods of polishing and etching for the macroscopic study of iron and steel. (Proposed at the Zurich Congress, 1895.)
Referee, E. Heyn, Carmerstrasse 15, Charlottenburg, Germany.

Problem 25.—To establish uniform methods of testing cast iron and finished castings. (Proposed at the Buda-Pesth Congress, 1901.)

Committee:

Chairman, R. Moldenke, Watchung, N. J.
American Members, Alex. E. Outerbridge, Jr., Albert Sauveur Thos. D. West.

Problem 26.—Tests with notched bars for ascertaining the relations between the different methods of testing and for fixing the numerical values representing the different properties of metals. (Proposed at the Buda-Pesth Congress, 1901.)
Referee, Ed. Sauvage, Rue Eugène Flachat 14, Paris, France.

Problem 27.—Ball-pressure tests for ascertaining the relations between the different methods of testing and for fixing the numerical values representing the different properties of metals. (Proposed at the Buda-Pesth Congress, 1901.)

Referees, J. A. Brinell, Chief Engineer, Jernkontoret, Stockholm, Sweden; G. Dillner, Director Royal Laboratory for Testing Materials, Stockholm, Sweden.

Problem 28.—The consideration of the magnetic and electric properties of materials in connection with their mechanical testing. (Proposed at the Buda-Pesth Congress, 1901.)

Referees, K. Hochenegg, Techn. Hochshule, Karlsplatz, Vienna, IV, Austria; M. von Hoor Tempik, Kgl. techn. Hochschule, Buda-Pesth, Hungary.

Problem 36.—Macroscopic examination of iron. (Resolution of Council, 1903.)

Referee, W. Ast, Nordbahnstrasse 50, Vienna, Austria.

Problem 37.—Microscopic examination of iron. (Resolution of Council, 1903.)

Referee, F. Osmond, 83 Boulevard de Courcelles, Paris, France

SECTION B.

NATURAL AND ARTIFICIAL BUILDING STONES AND THEIR CEMENTS.

Problem 7.—On the relation of chemical composition to the weathering qualities of building stones; the influence of smoke, especially sulphurous acid on building stones; the weathering qualities of roofing slates. (Proposed at the Zurich Congress, 1895.)

Committee:

Chairman, A. Hanisch, Schellinggasse 13, Vienna, I, Austria.
Vice-Chairman, P. Larivière, Quai Jemmapes 170, Paris, France.
American Members, J. F. Kemp, Mansfield Merriman.

Problem 9.—On rapid methods for determining the strength of hydraulic cements. (Proposed at the Zurich Congress, 1895.)

Committee:

Chairman, F. Berger, Rathhaus, Vienna, I, Austria.
Vice-Chairman (office vacant).
American Members, W. W. Maclay, Chas. McKenna.

Problem 10.—To digest and evaluate the resolutions of the conferences of 1884–1893 concerning the adhesive qualities of hydraulic cements.
Rejeree, R. Feret, Boulogne-sur-Mer, France.

Problem 11.—To establish methods for testing puzzolanas with the object of determining their value for mortars. (Proposed at the Zurich Congress, 1895.)

Committee:

Chairman, G. Herfeldt, Andernach, Germany.
Vice-Chairman, C. Segré, Ancona, Italy.
American Members, A. Lundteigen.

Problem 12.—Investigation on the behavior of cements as to time of setting and on the best method for determining the beginning and the duration of the process of setting. (Proposed at the Zurich Congress, 1895; enlarged in conformity with the resolution of the Buda-Pesth Congress, 1901.)

Committee:

Chairman, E. Candlot, rue d'Edimbourg 18, Paris, France.
Vice-Chairman, N. Lamine, Zabalkansky 9, St. Petersburg, Russia.
American Members, Spencer B. Newberry, Clifford Richardson.

Problem 13.—On the normal consistency of cement mortars for test specimens. (Proposed at the Zurich Congress, 1895.)

Committee:

Chairman, A. Greil, Rathhaus, Vienna, I, Austria.
Vice-Chairman (office vacant).
American Member, R. L. Humphrey.

Problem 29.—Determination of the liter weight of cement. The strength of neat hydraulic cements. Determination of a standard sand. (Proposed at the Buda-Pesth Congress, 1901.)
Referees, N. Belelubski, Rue Serpuchowskaja 4, St. Petersburg, Russia; F. Schuele, Eidg. Polytechnikum, Zurich, Switzerland.

Problem 30.—Determination of the simplest method for the separation of the finest particles in Portland cement by liquid and air processes. (Proposed at the Buda-Pesth Congress, 1901.)
Referee, M. Gary, Kgl. mech.-techn. Materialprüfungsamt Charlottenburg, Germany.

Problem 31.—On the behavior of cements in sea water. (Proposed at the Buda-Pesth Congress, 1901.)
Referee, H. Le Chatelier, Place du College de France 9, Paris, France.

Problem 32.—On accelerated tests of the constancy of volume of cements. (Proposed at the Zurich Congress, 1895.)

Committee:

Chairman, Bertram Blount, Broadway, Westminster, London, S. W., England.
Vice-Chairman (office vacant).
American Members, R. W. Lesley, Spencer B. Newberry.

Problem 33.—On the influence of the proportion of water and sand on the strength of Roman and other cements. (Proposed at the Buda-Pesth Congress, 1901.)
Referee, The Hungarian Society for Testing Materials, Buda-Pesth, Hungary.

SECTION C.

OTHER MATERIALS.

Problem 17.—On methods of testing tile pipes. (Proposed at the Stockholm Congress, 1897.)
Referee, M. Gary, Kgl. Materialprüfungsamt Charlottenburg, Germany.

Problem 18.—On the methods of testing the protective power of paints used on metallic structures. (Proposed at the Zurich Congress, 1895.)
Referees, Albert Grittner, Kobanyai ut 30, Buda-Pesth, Hungary; E. Ebert, Centralbahnhof, Munich, Germany.

Problem 19.—On uniform methods for testing lubricants. (Proposed at the Zurich Congress, 1895.)
Referee, N. Petroff, Zagorodny 70, St. Petersburg, Russia.

Problem 23.—On uniform methods for compression tests of wood.

Committee:

Chairman, Prof. A. Schwappach, Eberswalde, Germany.
Vice-Chairman, A. Wykander, Goeteborg, Sweden.
American Member, Filibert Roth.

Problem 35.—Study of the methods of testing caoutchouc. (Proposed at the Buda-Pesth Congress, 1901.)

Committee:

Chairman, E. Camerman, Rue Philippe Le Bon 73, Brussels, Belgium.
Vice-Chairman (office vacant).
American Member, R. G. Pearson.

SECTION D.

MISCELLANEOUS SUBJECTS.

Problem 22.—Considering that the resolutions formed by the International Conferences of Munich, Dresden, Berlin, Vienna and Zurich, for the purpose of attaining unity in the methods of testing materials, and the report of the Committee of the American Society of Mechanical Engineers do not agree in many points with the decisions arrived at by the French commission, it is proposed that the Council appoint a commission which shall prepare a report upon these differences, and proposal for ways and means of abolishing them.

Committee:

Chairman, N. Belelubski, Rue Serpouchowskaya 4, St. Petersburg, Russia.

Vice-Chairmen, A. Martens, Kgl. Materialprüfungsamt, Charlottenburg, Germany; E. Sauvage, l'Ecole des Mines, Paris, France.

American Members, Albert Ladd Colby, Gus. C. Henning, R. Moldenke, George F. Swain, George S. Webster, W. R. Webster, Walter Wood.

Problem 24.—On uniform nomenclature of iron and steel. (Resolution of Council, February 3, 1901.)

Committee:

Chairman, H. M. Howe, 27 West Seventy-third street, New York. N. Y.

Vice-Chairmen, L. Lévy, Rue de La Rochefoucauld 19, Paris, France; D. Tschernoff, Rue Pessatschenaia 25, St. Petersburg, Russia.

Secretary, Albert Sauveur, 446 Tremont street, Boston, Mass.

American Member, H. H. Campbell.

Problem 34.—Fixing a uniform definition and nomenclature of the bitumens. (Proposed at the Buda-Pesth Congress, 1901.)

Committee:

Chairman, G. Lunge, Eidg. Polytechnikum, Zurich, Switzerland.
Vice-Chairman, Jenoe Kovacs, Tataros (Post Mezoe Telegd), Hungary.
American Members, A. W. Dow, Clifford Richardson.

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